ATTACHMENT
7.1

ATTACHMENT
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9114347

M-00000612

01/23/01 LIST OF QUESTA MINE TECHNICAL DOCUMENTS (Section104(e) Submittal)

ATTACHMENT 7.1

DCN	DOCUMENT TYPE*	MONTH	DAY	YEAR	DOCUMENT AUTHOR	TITLE/SUBJECT MATTER	ATTACHMENT CODE	DOCUMENT STATUS
	R	Dec	00	1988	ENSR	Aquatic Ecosystem Survey of the Red River, New Mexico.	7.3	
	R	June	27	1994	ENSR	Molycorp – Mining Operation Site Assessment.	7.4	
	O		00	1991	Molycorp Inc.	Geological Maps	7.5	
	R	Nov	00	1976	Pennak, Robert W. (Thorne *Ecological Institute)*	Aquatic Ecosystems of Red River, New Mexico, in October, *1976. A Comparison with Conditions in October*, 1971.	7.6	
	R	Mar	00	1977	Pennak, Robert W. *(University of Colorado)*	Red River, New Mexico, Aquatic Ecosystems: March 1977 as *Compared with 1971 and 1976.*	7.7	
	R	Nov	11	1977	Pennak, Robert W. (University of Colorado)	Red River, New Mexico, Aquatic Ecosystems: October 1977 as Compared with October 1971 and October 1976.	7.8	
	R	Oct	01	1978	Pennak, Robert W. (University of Colorado)	Summary Comments on Aquatic Conditions in the Red River, New Mexico, in 1978 as Compared to 1971-1977.	7.9	
	R	Dec	00	1979	Pennak, Robert W. (University of Colorado)	Ecosystem Conditions in the Red River in the Late Summer of 1979: Effects of Abnormally High Runoff.	7.10	
	R	Oct	00	1981	Pennak, Robert W. (University of Colorado)	Aquatic Ecosystem Conditions in the Red River, New Mexico, in July, 1981.	7.11	
	R	Jan	00	1983	Pennak, Robert W. (University of Colorado)	Aquatic Ecosystem Conditions in the Red River, New Mexico, in October, 1982.	7.12	
	R	Jan	00	1984	Pennak, Robert W. (University of Colorado)	Aquatic Ecosystem Conditions in the Red River, New Mexico; October 1983.	7.13	
	R	Dec	00	1977	Questa Molybdenum Company	Geological Report Questa Project 1975-1977.	7.14	
	R	Oct	00	1997	RGC	Study of Groundwater Flow and Tailings Seepage near Questa, New Mexico Appendices A-E.	7.15	
	R	Oct	00	1997	RGC	Study of Groundwater Flow and Tailings Seepage near Questa, New Mexico.	7.16	
	R	Oct	00	1997	RGC	Three Dimensional Geometric Model of Molycorp's Questa Tailings Facility.	7.17	
	R	Mar	00	1998	RGC	Questa Tailings Facility Errata Report.	7.18	
	R	Nov	00	1999	RGC	Progress Report on Questa Waste Rock Investigation: Workplans for Routine Monitoring, Geochemical and Physical Characterization.	7.19	
	R	Mar	00	2000	RGC	Progress Report: Questa Waste Rock Pile Monitoring and Characterization Study.	7.20	
	R	Jun	00	2000	RGC	Water and Chemical Load Balance for Questa Tailings Facility, Questa, New Mexico.	7.21	
	R	Jul	00	2000	RGC	Surface Erosion and Stability Analysis Questa Tailings Facility, New Mexico.	7.22	

DOCUMENT TYPE: C = Correspondence, O = Other, R = Report

01/23/01 LIST OF QUESTA MINE TECHNICAL DOCUMENTS (Section104(e) Submittal)

DCN	DOCUMENT TYPE*	MONTH	DAY	YEAR	DOCUMENT AUTHOR	TITLE/SUBJECT MATTER	ATTACHMENT CODE	DOCUMENT STATUS
	R	Jul	00	2000	RGC	Evaluation of Closure Alternatives for Tailings Facility, Questa, New Mexico.	7.23	
	R	Nov	00	2000	RGC	Mine Site Borrow Materials and Rooting Zone Investigation, Questa NM.	7.24	
	R	Nov	00	2000	RGC	Water Balance Study for Questa Mine, New Mexico.	7.25	
	R	Nov	00	2000	RGC	As-Built Report – Storage Cover Test Plot Study, Questa *Tailings Facility, New Mexico*	7.26	
	R	Nov	00	2000	RGC	As-Built Report – Infiltration Test Plots for Mine Rock Piles, Questa Mine, New Mexico	7.27	
	R	Jan	00	2001	RGC	Integrated Geochemical Load Balance for Straight Creek, *Sangre De Cristo Mountains, New Mexico.*	7.28	Interim
	R	Jan	00	2001	RGC	Background Study Data Report, Questa Mine, New Mexico	7.29	Interim
	R	Jun	00	2000	RGC	Progress Report: Results of Phase 1 Physical Waste Rock Characterization Questa Mine, New Mexico.	7.30	
	R	Nov	00	2000	RGC	Interim Mine Site Characterization Study, Questa Mine , New Mexico	7.31	
	R	Apr	23	1997	Schafer, William M.	Expert Report.	7.32	
	R	Oct	17	1997	Souder Miller & Associates	Installation of Molycorp Tailings Area Monitoring and Extraction Wells – Design of Pumping and Water Discharge System.	7.33	
	R	Sept	30	1998	Souder Miller & Associates	Evaluation of Tailings Area Seepage Interception System.	7.34	
	R	Mar	17	2000	Souder Miller & Associates	1999 Hydrogeologic Investigation.	5.b.3	
	R	May	30	2000	Souder Miller & Associates	Mine Area Slug, Pumping, and Recovery Tests.	7.35	
	R	Jun	15	2000	Souder Miller & Associates	Mill Well #1 Pumping Test Report.	7.36	
	R	Apr	13	1995	SPR	Discussion of Geology, Hydrogeology, and Water Quality of the Tailings Area, Molycorp Facility, Taos County, New Mexico.	5.b.3	
	R	Apr	21	1995	SPR	Progress Report on the Geology, Hydrogeology, and Water Quality of the Mine Area, Molycorp Facility, Taos County, New Mexico.	7.37	Progress Report
	R	Apr	13	1995	SRK	Questa Molybdenum Mine Geochemical Assessment.	7.38	Final
	R	Apr	00	1996	SRK	Questa Tailings Disposal Facility Assessment of Acid Generating Potential.	7.39	
	R	Jan	00	1997	SRK	Questa Tailings Disposal Facility Drilling Report and Preliminary Cover Modeling.	7.40	Interim
	R	Nov	04	1997	SRK	*Questa Tailings Facility Geochemical Testing.*	7.41	Final
	R	Apr	23	1997	TRC (Ian Hutchison)	Questa Mine Site Expert Report.	7.42	

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DCN	DOCUMENT TYPE*	MONTH	DAY	YEAR	DOCUMENT AUTHOR	TITLE/SUBJECT MATTER	ATTACHMENT CODE	DOCUMENT STATUS
	R	Dec	1	2000	URS Corporation	Mine Rock Pile Erosion and Stability Evaluations Questa Mine	7.43	Interim
	R	Jan	00	2001	URS Corporation	Stormwater and Seepage Interception Systems Questa Mine, New Mexico.	7.44	Report
	R	Jul	4	2000	Vail Engineering, Inc.	Analysis of Acid Rock Drainage in the Middle Reach of the Red River, Taos County, New Mexico.	7.45	Interim

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DCN	DOCUMENT TYPE*	MONTH	DAY	YEAR	DOCUMENT AUTHOR	PREPARED FOR **	TITLE/SUBJECT MATTER	DOCUMENT STATUS
	R	Apr	00	1997	Chadwick Ecological Consultants	Molycorp	Aquatic Biological Assessment of the Red River, New Mexico, in the Vicinity of the Questa Molybdenum Mine.	
	R	Feb	00	1998	Chadwick Ecological Consultants	Molycorp	Fall 1997 Data Addendum Red River Aquatic Biological Assessment.	
	R	Jan	00	1999	Chadwick Ecological Consultants	Molycorp	Red River Aquatic Biological Monitoring 1998.	
	R	Jan	00	2000	Chadwick Ecological Consultants	Molycorp	Red River Aquatic Geological Monitoring 1999.	
	R	Nov	00	1971	EPA		A Water Quality Survey Red River and Rio Grande, New Mexico	
	R	Apr	00	1998	RGC	Molycorp	Questa Tailings Facility Revised Closure Plan Appendices A-I.	
	R	Apr	00	1998	RGC	Molycorp	Questa Tailings Facility Revised Closure Plan.	
	R	Sep	6	1999	RGC	Molycorp	Interim Report: Questa Waste Rock Pile Drilling, Instrumentation and Characterization Study.	Interim
	R	Jan	00	2000	RGC	Molycorp	Workplan for Background Characterization Study, Questa Mine, New Mexico.	
	R	Jan	00	2000	RGC	Molycorp	Workplan for Comprehensive Water and Load Balance Study, Questa Mine New Mexico.	
	R	Mar	00	2000	RGC	Molycorp	Progress Report: Questa Waste Rock Pile Monitoring and Characterization Study.	
	R	Jun	00	2000	RGC	Molycorp	Interim Background Characterization Study, Questa Mine, New Mexico.	
	R	Mar	17	2000	Souder Miller & Associates	Molycorp	1999 Hydrogeologic Investigation.	
	R	Jun	15	2000	Souder Miller & Associates	Molycorp	Mill Well #1 Pumping Test Report.	
	R	Jul	14	1993	SPR	Molycorp	Preliminary Investigation of the Potential Impact of the Rewatering of Molycorp's Deeper Underground Mine on the Red River near Questa, New Mexico.	
	R	Sep	23	1993	SPR	Molycorp	Hydrogeologic Evaluation of Tailings Ponds.	
	R	Apr	13	1995	SPR	Molycorp	Discussion of Geology, Hydrogeology, and Water Quality of the Tailings Area, Molycorp Facility, Taos County, New Mexico.	
	R	Apr	13	1995	SRK	Molycorp	Questa Molybdenum Mine Geochemical Assessment.	Final
	R	Jun	30	1997	SRK	Molycorp	Questa Tailings Disposal Facility Geochemical Testing.	Interim
	R	Nov	04	1997	SRK	Molycorp	Questa Tailings Facility Geochemical Testing.	Final
	R	Jun	00	1989	Vail Engineering	Molycorp	A Geochemical Investigation of the Origin of Aluminum Hydroxide Precipitate in the Red River, Taos County, New	

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DCN	DOCUMENT TYPE*	MONTH	DAY	YEAR	DOCUMENT AUTHOR	PREPARED FOR **	TITLE/SUBJECT MATTER	DOCUMENT STATUS
							Mexico.	
	R	Jul	09	1993	Vail Engineering	Molycorp	Interim Study of the Acidic Drainage to the Middle Red River, Taos County, New Mexico.	
	R	Jul	04	2000	Vail Engineering	Molycorp	Analysis of Acid Rock Drainage in the Middle Reach of the Red River, Taos County, New Mexico.	Interim
	R	Jun	00	1994	Woodward-Clyde	Molycorp	Excerpts (tables, raw chemical data) from Report Titled "Field Observations of the NMED April 1994 Sampling Event at the Molycorp Questa Mine: Questa, New Mexico".	

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ATTACHMENT
7.3

Molycorp, Inc.

Questa, New Mexico

ENSR

Aquatic Ecosystem Survey of the Red River, New Mexico

ENSR Consulting and Engineering

(Formerly ERT)

December 1988

Document Number 4710-001

M-00000618

4710-001

AQUATIC ECOSYSTEM SURVEY OF THE RED RIVER, NEW MEXICO

Prepared for

MOLYCORP, INC.
Questa, New Mexico

Prepared by

ENSR CONSULTING AND ENGINEERING
Fort Collins, Colordo

December 1988

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1.0 INTRODUCTION

In June 1988, a proposal was submitted by ENSR Consulting and Engineering (formerly ERT) to Molycorp, Inc. to conduct an aquatic ecology monitoring program in the Red River, located in north central New Mexico in the vicinity of Questa and Red River, New Mexico. This report describes the sampling effort that occurred on the Red River in October, 1988 and the results of that effort.

In the early 1970's, concern developed for the water quality of the Red River which receives discharge from municipal treatment facilities as well as discharge from Molycorp's mining and milling operation. To determine if these sources were impacting the Red River aquatic ecology, several studies were completed on the river between 1971 and 1985. R. Pennak conducted aquatic surveys of the river between 1971 and 1982. In addition, the Surveillance and Standards Section of New Mexico Environmental Improvement Division (Surface Water Quality Bureau) performed surveys of the Red River in 1984 and 1985. In order to provide data for comparison to this historical information, an effort was made on the part of ENSR to measure not only density and diversity of benthic and algal populations, but also to calculate various community parameters (e.g., diversity indices, BCI, community similarity indices) that would allow better estimations of spatial and temporal community changes.

2.0 MATERIALS AND METHODS

2.1 Sample Site Locations and Times

The Red River lies in the Rio Grande watershed in northern New Mexico. The headwaters of the Red River are found in the Sangre de Cristo Mountains. Approximately 6 miles upstream of the town of Red River, at an elevation of 9,400 feet, the East and Middle forks of the river merge to form the main channel of the Red River. The river flows in a westerly direction for approximately 27 miles and eventually empties into the Rio Grande at an elevation of 6,500 feet. At its mouth, the drainage area of the Red River is 190 square miles (Jacobi and Smolka 1984).

A total of seven stations were located on the Red River upstream of and downstream of the town of Questa, New Mexico on October 10, 11, and 12, 1988. Descriptive locations of the stations are as follows:

- Station 1 - On the Red River approximately 200 meters upstream of Molycorp's mill fence line.
- Station 1a - On the Red River near the Goat Hill Campground, or approximately one mile downstream of Molycorp's mining/milling complex.
- Station 2 - On the Red River just upstream of the gaging station at Questa Ranger District and approximately two miles downstream of Station 1a.
- Station 3 - On the Red River approximately 150 meters upstream of Pope Creek.
- Station 4 - On Pope Creek approximately 50 meters upstream of its confluence with the Red River. This station was dry and was not sampled.
- Station 5 - On the Red River approximately 150 meters upstream from the fish hatchery.
- Station 6 - On the Red River approximately 0.5 mile downstream from the fish hatchery.
- Station 7 - On the Red River immediately upstream of its confluence with the Rio Grande near La Junta campground.

The stations were sampled between October 10 and October 12 at various times, as follows:

- Station 1 - October 12; 1015-1045 hours
- Station 1a - October 10; 1730-1800 hours
- Station 2 - October 12; 0900-0945 hours
- Station 3 - October 11; 1400-1430 hours
- Station 5 - October 11; 1635-1700 hours
- Station 6 - October 11; 1530-1600 hours
- Station 7 - October 11; 1100-1130 hours

2.2 Collection of Benthic Macroinvertebrates

At each station (excluding Station 7) three samples were gathered using a Surber sampler. At Station 7, three samples were collected using a delta-frame dip net (D-net) for a given time interval (30 to 35 seconds). A D-net, rather than a Surber sampler, was used at Station 7 because of the depth (>2 feet) and swiftness of the water. The Surber samples were collected from areas in the river that best represented substrate conditions. The sampler was placed on the substrate with its opening facing upstream. The substrate material contained within the one square foot sampling frame was then disturbed by hand until all of the material had been sufficiently disturbed to remove all or most of the benthic organisms. This effort usually took from 60 to 80 seconds. The sampled material was then placed in a sieve bucket where excess debris and sediment were removed by swirling the bucket in the stream. The remaining contents were placed in a labeled 16-ounce widemouth polypropylene jar partially filled with water. The sample was preserved with formalin to a final concentration of about 10 percent. The sample was placed in a cooler for storage until shipment back to the laboratory.

2.3 Collection of Periphyton

At each station a known area of substrate, usually rock, was scraped with a pocket knife and the contents placed in a 2-ounce jar and preserved with 5 percent formalin. Samples were taken, to the extent possible at the particular station, from rocks that had a visible growth of macrophyton, that is, plant material including algae and non-algal plants such as bryophytes. This was done in order to be reasonably consistent with past studies performed by R. Pennak. After each sample was collected, the area scraped was measured and recorded into the field notebook. The areas from which samples were taken at each station are as follows:

- Station 1 - 18 in^2
- Station 1a - 36 in^2
- Station 2 - Very Scarce; a dispersed sample taken, no area measured.
- Station 3 - 16 in^2
- Station 5 - 36 in^2
- Station 6 - 16 in^2
- Station 7 - 20 in^2

At locations where macrophyton growth was dense, the collected macrophyton was gently rinsed of excess inorganic material (sand, silt, etc.) before being placed in the sample container. Each sample container was labeled and placed in a cooler for transport to ENSR's Fort Collins, Colorado office.

2.4 Instream Measurements and Collection of Water

Four water quality measurements were taken at each station: pH, dissolved oxygen (DO, mg/L), temperature (°C), and conductivity (µmhos). Measurements of pH were taken with an Orion Model 211 portable pH meter and probe. Prior to each reading, the pH meter was calibrated to pH 7.0 using a standard buffer solution. At the beginning of each sampling day, the pH meter was calibrated to pH 7.0 and 10.0 using standard buffer solutions. Dissolved oxygen and temperature were measured using a calibrated YSI Model 54 ARC DO/temperature meter. Prior to each day's use, the meter was air calibrated to existing temperature and altitude conditions according to manufacturers instructions. Electrical conductivity was measured in µmhos/cm using a YSI Model 31 SCT meter. Conductivities were temperature compensated in the field. All data were recorded (in ink) into a waterproof field book.

Water was collected at each station to be analyzed for selected metals and conventional parameters. A single one-liter plastic container was used to collect water for metals; another was used to collect water for the conventional parameters. The containers were labeled prior to sample collection. To fill the containers, the bottles were submerged near the center of the stream channel (thalweg). The samples were kept on ice and no preservatives were added since the samples were delivered at the end of each day to Molycorp's on-site analytical laboratory. Once in the laboratory, the samples for trace metals analyses were acidified to pH 2 using nitric acid.

The conventional parameters measured included pH (in-lab), total suspended solids (TSS), total dissolved solids (TDS), turbidity, sulfate, cloride, and total alkalinity. Both dissolved and suspended portions were analyzed for the following metals: cadmium, lead, iron, manganese, molybdenum, zinc, copper, aluminum, and barium.

2.5 Sample Analysis

2.5.1 Benthic Macroinvertebrates

Benthic (and periphyton) samples were transported to ENSR's office in Fort Collins via automobile. The samples were then logged in and given a unique sample number. The sample preservative was checked and the samples were turned over to ENSR's taxonomic subcontractor, Mr. Henry Zimmerman, for analysis.

Sample material for macroinvertebrate analysis was first rinsed of excess formalin in a standard No. 30 (0.495 um) sieve. The rinsed contents of each sample were placed in a white enamel pan with water, and carefully sorted from the debris. Sorted benthic organisms were placed in vials containing 70 percent isopropyl alcohol (2-propanol). The organisms were counted and identified to the lowest taxonomic level practical. Most organisms were identified to genus and some to species.

In addition to identification and enumeration, total sample biomass per replicate sample was determined. Biomass was expressed as dry weight. For each sample, the organisms were placed in pre-weighed aluminum dishes and dried for 24 hours at 103 to 105°C. The samples were then weighed to the nearest .0001 grams on a A & D Model ER-180A analytical balance.

Data analysis provided several benthic community measurements for each station. In addition to faunal density (No./m2) and total taxa, percent relative abundance, total biomass (gm dry weight/m2), species diversity, species evenness, and Biotic Condition Index (BCI) were also calculated. These indices were added to the data analysis in order to make ENSR's data more comparable to other recent data collected by the State of New Mexico. Finally, a community similarity index (Morisita's) was used to compare the benthic communities of the sampling stations, and stations were statistically compared to one another using Kruskal-Wallis nonparametric analysis of variance tests to determine if significant (α0.05) changes in the benthic community occur moving from upstream to downstream sites.

The index of species diversity for these data was the Shannon-Wiener index (Weber 1973; Brower and Zar 1977). The Shannon-Wiener index (H'; also symbolized by "d" in Weber 1973) considers both the number of taxa present at a station and the distribution of individual organisms within each taxa. The biotic condition index is designed to provide a system for evaluating existing macroinvertebrate community conditions based upon their biotic potential (Winget 1985). The potential of a community (CTQp; Predicted Community Tolerance Quotient) is determined by examining four chemical and physical characteristics of the stream, those being: total alkalinity, sulfate concentration, percent gradient, and substrate type. These characteristics were determined for each station, alkalinity and sulfate by actual measurement, substrate by on-site observation, and percent gradient by measurements from 1:24,000 U.S.G.S. topographic maps. The Actual Community Tolerance (CTQa) was then calculated from tolerance quotients assigned to each benthic invertebrate taxa found at a particular station. The BCI is determined by dividing the predicted value by the actual value. A CTQa greater than 75 with a BCI less than 75 would indicate a poor quality environment, a CTQa between 61 and 74 and a BCI between 76 and 89 would indicate a moderately degraded environment, and a high quality environment would be indicated by a CTQa less than 60 and a BCI greater than 90 (Smolka and Jacobi 1986).

2.5.2 Periphyton

The periphyton (including macrophyton) samples were prepared for identification, enumeration, and biomass analysis. Algae were identified at least to the genus level. For all groups except Bacillariophyta (diatoms), relative composition was estimated by counting the number of organisms present in five horizontal strips on a Sedgewick-Rafter cell. Hydrogen peroxide (30 percent) was used to clear diatom frustules of organic matter. The diatoms were placed on heated coverslips which, after evaporation of the hydrogen peroxide, were mounted on slides using Hyrax mounting medium (Ward and Dufford 1979).

Ash free dry weight (AFDW) of the periphyton/macrophyton was determined in all samples. The plant material was placed in pre-dried and pre-weighed crucibles and dried initially at 105°C for 24 hours. After the samples were cooled and weighed, they were ashed in a muffle furnace at 550+5°C for approximately 1 hour. The samples were then rewetted to restore the water of hydration to clay and other inorganic material, redried at 105°, and weighed. AFDW was determined by subtracting the ash weight from the dry weight.

3.0 RESULTS

3.1 Benthic Macroinvertebrates

3.1.1 Benthic Density and Number of Taxa

A total of 20 benthic macroinvertebrate taxa were identified from all the stations on the Red River (Table 3-1). The number of taxa present at each station varied from 3 at Station 2 to 12 at Station 6. Moving downstream from Station 1, there was a steady decline in the number of taxa at the first three stations (Figure 3-1). However, the number climbed again at Station 3 and remained approximately the same throughout the rest of the river. The total density of macroinvertebrates (excluding Station 7 where only qualitative samples were taken) was considerably higher at Station 6 (1972.67 organisms/m^2) when compared to the other stations (Figure 3-2). While variation existed at any single station in the benthic densities in each replicate (Table 3-2), there was a basic consistency at most stations. One replicate at each station, though, tended to be lower than the other replicates. In general, the density pattern is similar to the taxa pattern with lower densities at Stations 1, 1a, and 2, and higher densities at the downstream stations. As one might expect, the changes in macroinvertebrate dry weight (grams/m^2) are very similar to the density changes, with the greatest dry weight (1.8034) being measured at Station 6 (Table 3-3, Figure 3-3).

Several benthic species were found at all stations, while others were identified only at one site. At Station 1, for example, approximately 50 percent of the organisms were either Drunella grandis (Mayfly) or Arctopsyche sp. (caddisfly) (Table 3-4). D. grandis was found at three additional stations, but at much lower percentages, and Arctopsyche sp. was additionally found only at Station 1a at 9.1 percent. In general, there appears to be a shift in community composition from the upstream stations to the downstream stations. At Stations 1 through 5, a larger part of the community was made up of either mayflies (Ephemeroptera) or stoneflies (Plecoptera). In the middle and downstream stations (3 to 7) caddisflies (Trichoptera) comprised an increasingly large percentage of the population. At Station 6, for example, over 71 percent of the benthic organisms were of the genus Hydropsyche sp. This genus was not identified at all in samples from Stations 1, 1a, and 2. Given the overall greater

TABLE 3-1

SUMMARY OF MEAN BENTHIC MACROINVERTEBRATE DENSITIES AND VARIOUS COMMUNITY PARAMETERS

Taxa	Station 1	1a	2	3	5	6	7[1]
Ephemeroptera							
Baetis sp.	10.76[2]	14.35		50.21	57.39	143.47	37.3
Drunella grandis	57.39		10.76	14.35	14.35		
Rhithrogena sp.	28.69	43.04	32.28	32.28	172.16	139.88	0.3
Plecoptera							
Isogenoides elongatus	10.76	3.59		7.17	10.76	7.17	0.3
Pteronarcella badia	32.28	7.17	64.56	111.19	86.08	46.63	0.7
Coleoptera							
Optioservus sp.				3.59	7.17	25.11	17.3
Narpus sp.				3.59			
Trichoptera							
Arctopsyche sp.	50.21	7.17					
Apatania sp.	7.17						
Hydropsyche sp.				89.67	107.60	1405.97	58.0
Rhyacophila sp.	7.17					39.45	0.7
Brachycentrus americanus	17.93			7.17	3.59	114.77	
B. occidentalis							18.3
Diptera							
Atherix sp.	7.17	3.59		39.45	28.69	28.69	1
Hexatoma sp.						10.76	2
Tipula sp.						3.59	
Wiedmannia sp.					3.59		
Tanyderidae				3.59			
Hemiptera					3.59		

TABLE 3-1 (CONTINUED)

Taxa	Station 1	1a	2	3	5	6	7[1]
Turbellaria							
Dugesia sp.						7.17	
Total (No./m^2)	229.55	78.91	107.60	362.25	494.96	1972.67	135.9
Total Taxa	10	6	3	11	11	12	10
Diversity (H')	2.92	1.96	1.30	2.68	2.56	1.66	
Evenness (J')	0.88	0.76	0.82	0.77	0.74	0.46	
CTQp	50	50	50	50	50	50	
CTQa	29.10	30.50	31.00	60.82	59.18	50.25	
CTQd	29.43	32.11	28.65	54.65	54.53	53.60	
BCI	171.82	163.93	161.29	82.21	84.49	99.50	

[1]Only qualtitative samples were taken at Station 7; values only represent numbers/replicate.

[2]No./m^2, mean of 3 replicates.

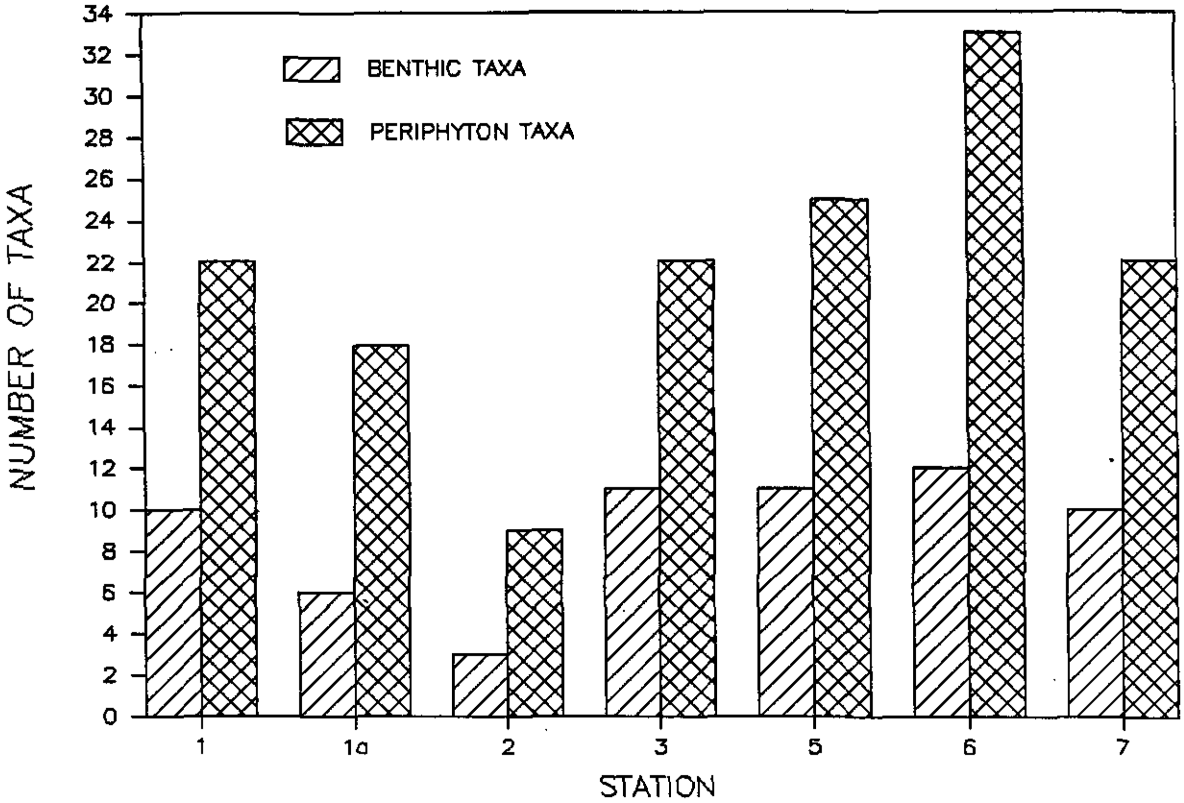

Figure 3—1. Number of Benthic and Periphyton Taxa at Each Station on the Red River.

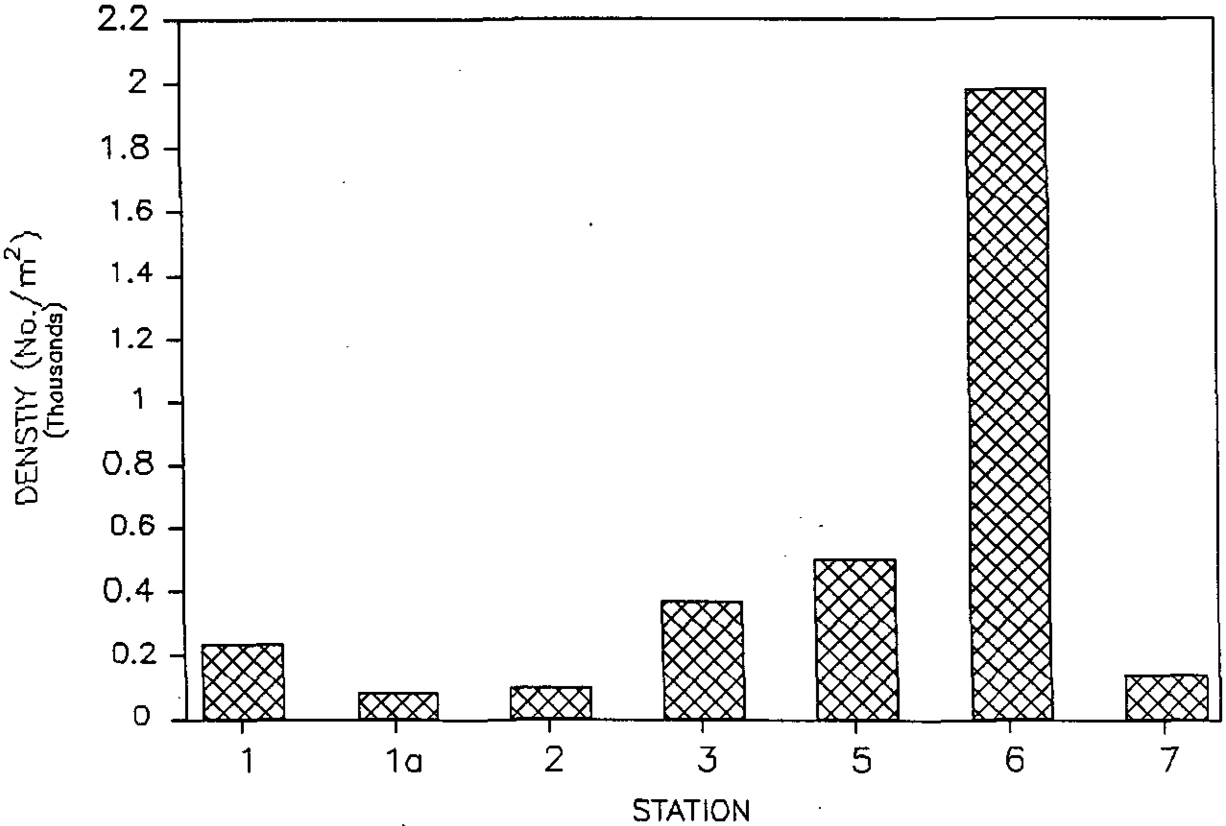

Figure 3–2. Mean Density of Benthic Organisms at Each Station on the Red River.

TABLE 3-2

DENSITIES OF THE BENTHIC MACROINVERTEBRATE TAXA
IN EACH REPLICATE FROM EACH STATION

Taxa	Station/Replicate					
	1/a	1/b	1/c	1a/a	1a/b	1a/c
Ephemeroptera						
Baetis sp.		32.28		10.76	32.28	
Drunella grandis		118.36	53.80			
Rhithrogena sp.	64.56		21.52		64.56	64.56
Plecoptera						
Isogenoides elongatus		10.76	21.52			10.76
Pteronarcella badia		64.56	32.28		10.76	10.76
Coleoptera						
Optioservus sp.						
Narpus sp.						
Trichoptera						
Arctopsyche sp.	21.52	64.56	64.56			21.52
Apatania sp.		21.52				
Hydropsyche sp.						
Rhyacophila sp.		21.52				
Brachycentrus americanus	10.76	43.04				
Brachycentrus occidentalis						
Diptera						
Atherix sp.			21.52	10.76		
Hexatoma sp.						
Tipula sp.						
Wiedmannia sp.						
Tanyderidae						
Hemiptera						
Turbellaria						
Dugesia sp.						
Density (No./m^2)	96.84	376.60	215.20	21.52	107.60	107.60
Total Taxa	3	8	6	2	3	4
Dry Weight (grams/m^2)	0.1130	0.8038	0.5800	0.1194	0.0699	0.1420

TABLE 3-2 (CONTINUED)

Taxa	Station/Replicate 2/a	2/b	2/c	3/a	3/b	3/c
Ephemeroptera						
Baetis sp.				21.52	53.80	75.32
Drunella grandis	10.75	21.52			21.52	21.52
Rhithrogena sp.		53.80	43.04	53.80	21.52	21.52
Plecoptera						
Isogenoides elongatus				10.76	10.76	
Pteronarcella badia	10.76	96.84	86.08	10.76	193.68	129.12
Coleoptera						
Optioservus sp.						10.76
Narpus sp.						10.76
Trichoptera						
Arctopsyche sp.						
Apatania sp.						
Hydropsyche sp.				10.75	43.04	215.20
Rhyacophila sp.						
Brachycentrus americanus					10.76	10.76
Brachycentrus occidentalis						
Diptera						
Atherix sp.				32.28	32.28	53.80
Hexatoma sp.						
Tipula sp.						
Wiedmannia sp.						
Tanyderidae						10.76
Hemiptera						
Turbellaria						
Dugesia sp.						
Density (No./m^2)	21.52	172.16	129.12	139.88	387.36	559.52
Total Taxa	2	3	2	6	8	10
Dry Weight (grams/m^2)	0.0398	0.3163	0.2507	0.3723	0.6413	0.7618

TABLE 3-2 (CONTINUED)

Taxa	Station/Replicate					
	5/a	5/b	5/c	6/a	6/b	6/c
Ephemeroptera						
Baetis sp.	64.56	32.28	75.32	225.96	43.04	161.40
Drunella grandis	21.52	10.76	10.76			
Rhithrogena sp.	64.56	139.88	312.04	118.36	107.60	193.68
Plecoptera						
Isogenoides elongatus	10.76	21.52		10.76	10.76	
Pteronarcella badia	150.64	86.08	21.52	64.56	64.56	10.76
Coleoptera						
Optioservus sp.	21.52			32.28	43.04	
Narpus sp.						
Trichoptera						
Arctopsyche sp.						
Apatania sp.						
Hydropsyche sp.	150.64	129.12	43.04	2055.16	1560.20	602.56
Rhyacophila sp.				21.52	96.84	
Brachycentrus americanus		10.76		172.16	172.16	
Brachycentrus occidentalis						
Diptera						
Atherix sp.	32.28	10.76	43.04	32.28	10.76	43.04
Hexatoma sp.				32.28		
Tipula sp.				10.76		
Wiedmannia sp.	10.76					
Tanyderidae						
Hemiptera	10.76					
Turbellaria						
Dugesia sp.				10.76	10.76	
Density (No./m^2)	538.00	441.16	505.72	2786.84	2119.72	1011.44
Total Taxa	10	8	6	12	10	5
Dry Weight (grams/m^2)	0.4777	0.6714	0.3594	2.5900	1.7603	1.0599

TABLE 3-2 (CONTINUED)

Taxa	Station/Replicate 7/a[1]	7/b[1]	7/c[1]
Ephemeroptera			
Baetis sp.	38	55	19
Drunella grandis			
Rhithrogena sp.			1
Plecoptera			
Isogenoides elongatus		1	
Pteronarcella badia	1		1
Coleoptera			
Optioservus sp.	1	51	
Narpus sp.			
Trichoptera			
Arctopsyche sp.			
Apatania sp.			
Hydropsyche sp.	12	156	6
Rhyacophila sp.			2
Brachycentrus americanus			
Brachycentrus occidentalis	2	53	
Diptera			
Atherix sp.		3	
Hexatoma sp.	2	4	
Tipula sp.			
Wiedmannia sp.			
Tanyderidae			
Hemiptera			
Turbellaria			
Dugesia sp.			
Density (No./m^2)	56	323	29
Total Taxa	6	7	5
Dry Weight (grams/m^2)	0.0403	0.2928	0.0242

[1] Quantitative samples were not collected at Station 7. Those values only represent number/replicate, not No. or grams/m^2.

TABLE 3-3

SUMMARY OF SOME BIOLOGICAL AND CHEMICAL PARAMETERS
FROM SEVEN STATIONS ON THE RED RIVER

Station	Benthic Taxa	Mean No. of Benthic Organisms ($No./m^2$)	Mean Benthic Dry Weight (g/m^2)	Periphyton Taxa	Periphyton Ash Free Dry Weight per Sample ($g/100\ cm^2$)	Percent Bacillariophyta	Percent Chlorophyta	Percent Cyanophyta	pH (Field)	Dissolved Oxygen (mg/l)	Temperature (°C)	Electrical Conductivity (µmhos/cm)
1	10	229.55	0.4989	22	0.3967	10	0	90	7.98	9.1	4.0	150
1a	6	78.91	0.1104	18	0.5644	10	0	90	7.6	8.9	8.1	205
2	3	107.60	0.2023	9	0.0011	<1	0	>99	7.45	9.1	4.5	198
3	11	362.25	0.5918	22	0.2225	15	0	85	7.7	8.1	10.5	290
5	11	494.96	0.5028	25	0.0844	20	0	80	8.05	8.4	12.5	275
6	12	1972.67	1.8034	33	0.6272	30	0	70	7.9	7.9	13.0	285
7[2]	10	135.90	0.1191	22	0.3148	10	30	60	8.1	8.7	9.5	280

[1] Mean of three replicates.

[2] Only qualitative replicates were taken at Station 7. Benthic densities and dry weights are therefore only per replicate, not per area.

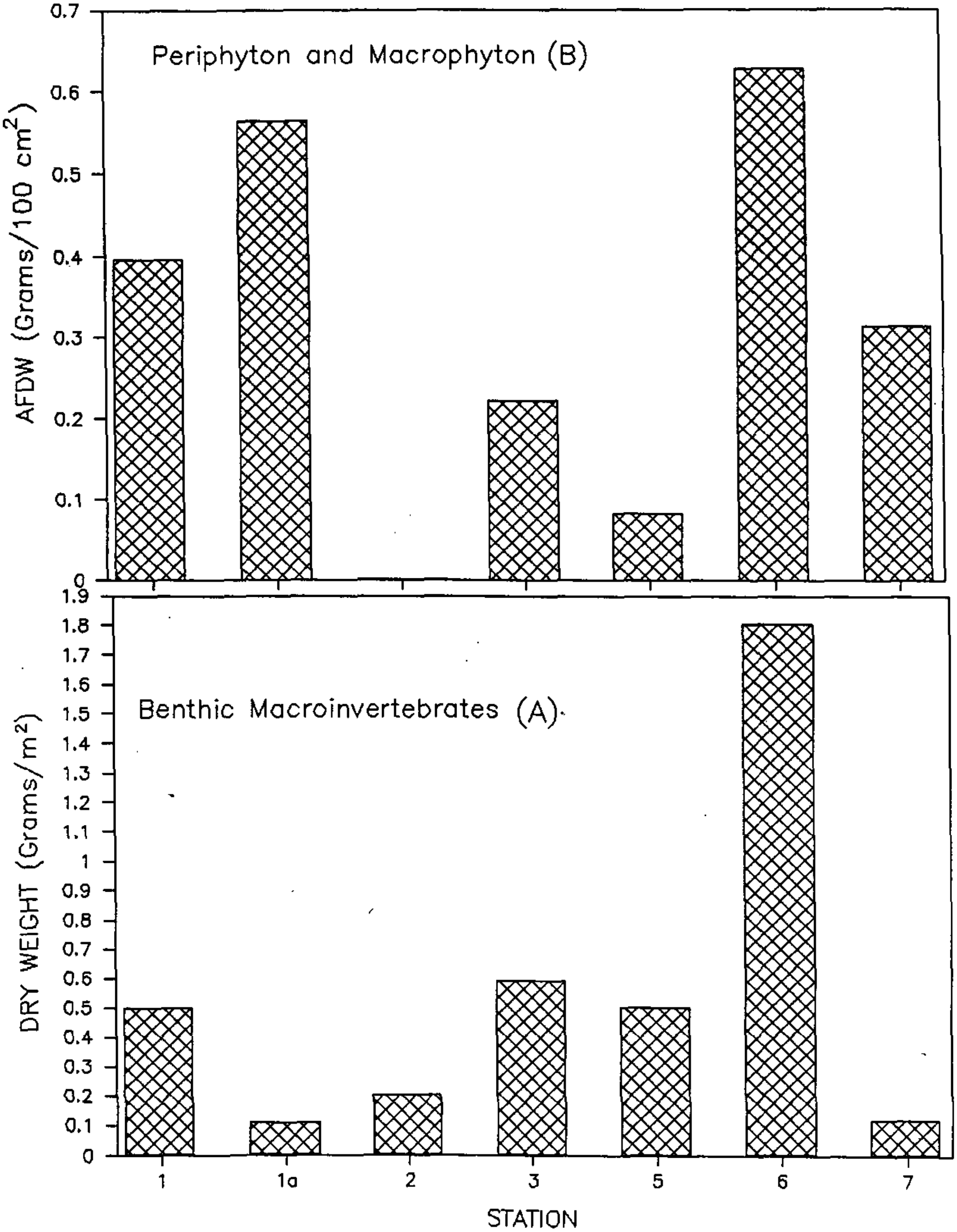

Figure 3–3. Dry Weight of Benthic Macroinvertebrates (A) and AFDW of Periphyton and Macrophyton (B).

TABLE 3-4

MEAN PERCENT RELATIVE ABUNDANCE OF EACH BENTHIC TAXON

AT EACH STATION ON THE RED RIVER

Taxa	Station 1	1a	2	3	5	6	7
Ephemeroptera							
Baetis sp.	4.7	18.2		13.9	11.6	7.3	27.4
Drunella grandis	25.0		10.0	4.0	2.9		
Rhithrogena sp.	12.5	54.5	30.0	8.9	34.8	7.1	0.22
Plecoptera							
Isogenoides elongatus	4.7	4.5	60.0	2.0	2.2	0.36	0.22
Pteronarcella badia	14.1	9.1		30.7	17.4	2.4	0.52
Coleoptera							
Optioservus sp.				0.99	1.4	1.3	12.7
Narpus sp.				0.99			
Trichoptera							
Arctopsyche sp.	21.9	9.1					
Apatania sp.	3.1						
Hydropsyche sp.				24.8	21.7	71.3	42.7
Rhyacophila sp.	3.1					2.0	0.52
Brachycentrus americanus	7.8			2.0	0.73	5.8	
Brachycentrus occidentalis							13.5
Diptera							
Atherix sp.	3.1	4.5		10.9	5.8	1.5	0.74
Hexatoma sp.						0.55	1.5
Tipula sp.						0.18	
Wiedmannia sp.					0.73		
Tanyderidae				0.99			
Hemiptera					0.73		
Turbellaria							
Dugesia sp.						0.36	

density of numbers at Station 6, even lower percentages may be a result of greater actual numbers when compared to stations with lower benthic densities. Brachycentrus americanus comprised 7.8 percent and 5.8 percent of the total benthic community at Stations 1 and 6, respectively. However, the actual densities at Stations 1 and 6 were 17.93 and 114.77 organisms/m^2, respectively.

3.1.2 Community Condition Parameters

The various community condition parameters that were calculated are shown in Table 3-1. The Shannon-Wiener diversity index (H') varied from 2.92 at Station 1 to 1.30 to Station 2. The low index at Station 2 is, for the most part, a result of only three taxa being found at that station. Despite this fact, the evenness of the benthic taxa (J') (which measures the distribution of organisms among all the taxa) at Station 2 was fairly high at 0.82 or 82 percent (Table 3-1). The highest evenness index was calculated at Station 1, which also had the highest H' value. The lowest evenness (0.46) was at Station 6, which had the second lowest Shannon diversity. This indicates that, although samples collected at Station 6 had the highest density as well as the highest number of taxa, the distribution of organisms among taxa was poor.

The BCI (biotic condition index) amd parameters used to calculate it are shown in Table 3-1. At the three farthest upstream stations (1, 1a, and 2) the BCI's were all 161 or above with the highest value of 171.82 being calculated at Station 1. Also at these three stations, the CTQa, or actual community tolerance quotient, is low. Based upon these two parameters, therefore, it may be said that the benthic communities at Stations 1, 1a, and 2 are high quality. At the next three stations, the BCI drops and the CTQa increases, indicating a decrease in the quality of the community. Another factor, however, must be considered at these stations. Note that in each case, the CTQd (dominance community tolerance quotient) varies from the CTQa by more than three units. Winget (1985) states that if this is the case, than the community may be dominated by more tolerant species and the BCI may not be an accurate measure of community quality. At Station 6 the difference between the CTQd and the CTQa is 3.35 and therefore the BCI may be appropriate at this station;

such is not the case at Stations 3 and 5. At the three downstream stations (excluding Station 7) it may be interpreted that the quality of the benthic community is lower, perhaps significantly so, than the upstream stations.

Morisita's index of community similarity was calculated between each station, except 7 (Table 3-5). Based upon the BCI, one might expect a distinct separation between the upper and lower stations; such is not the case. The greatest similarity, for example, lies between Stations 5 and 1a, with an index of 0.81. Station 6, however, is very dissimilar from Stations 1, 1a, and 2, with similarity indices of 0.06, 0.12, and 0.05, respectively. The indices between 6, and Stations 3 and 5 are higher, with values of 0.56 and 0.52, respectively. Based upon these numbers, therefore, Station 6 is much more similar to Stations 3 and 5, than to the upstream stations. It can be assumed, although it can't be calculated, that Station 7 is probably more similar to Station 6 than to the upstream stations.

3.1.3 Statistical Analysis

Kruskal-Wallis analysis of variance was used to determine if a significant difference existed among the six stations at which quantitative benthic samples were collected. Four different parameters were analyzed: density, dry weight, Shannon-Wiener diversity (H'), and Shannon-Wiener Evenness (J'). It was found that only density and dry weight were significantly different among the stations at an alpha level of 0.05. The actual probabilities associated with the analysis were: density, 0.017; dry weight, 0.028; diversity, 0.051, and evenness, 0.058. To determine between what stations the differences actually existed, a Student-Newman-Keuls multiple range test was used. In the case of density, Station 6 was significantly ($P=0.001$) different from all the other stations. Similarly, Station 6 had a significantly ($P\leq0.004$) higher measured dry weight than the remaining stations.

3.2 Periphyton

Blue-green algae dominated the periphyton populations at all stations (Table 3-3). At least 90 percent of the algae collected at Stations 1,

TABLE 3-5

MORISITA'S SIMILARITY INDEX
FOR THE BENTHIC COMMUNITY[1]

Station	Station 1	1a	2	3	5	6
1	—	.45	.29	.43	.45	.06
1a	.45	—	.46	.39	.81	.12
2	.29	.46	—	.13	.36	.05
3	.43	.39	.13	—	.78	.56
5	.45	.81	.36	.78	—	.52
6	.06	.12	.05	.56	.52	—

[1] Station 7 is excluded since samples from this station were not quantitative.

1a, and 2 were blue-green species. At Station 2, in fact, greater than 99 percent were blue-green algae. Only at Station 7 did any of the alga taxa belong to the division Chlorophyta (green algae).

The actual algal species that were identified, and their relative abundance within each division, are given in Table 3-6. The greatest number of taxa (33) were identified at Station 6; the lowest number (9) at Station 2. More diatom (Bacillariophyta) taxa were seen than any other group although their overall mass was less than the blue-green algae. Certain species were more commonly identified than others, including Achnanthes microcephala, A. minutissima, and Fragilaria vaucheriae. Of course, it was the blue-green algae that dominated the collected samples at all the stations. At all stations Oscillatoria spp. was found quite frequently although Lyngbya nana made up 60 percent of the blue-green algae found at Station 2.

Table 3-6 presents the actual ash-free dry weights of all the periphyton samples. The amount of plant material differed noticeably between stations, with most of the weight being attributed not to algae but to bryophytes (moss) that were collected with the periphyton. The most material was collected at Station 1a; the least at Station 2 where all of the material was algal. To allow for a better comparison of the plant weights, all AFDWs were converted to grams/100 cm^2 (Table 3-3). When this is done, it can be seen that the greatest amount of material per 100cm^2 (0.6272 g) was found at Station 6 (Figure 3-3).

3.3 Chemical Parameters

Dissolved oxygen was measured at higher concentrations in the three upstream stations and declined downstream (Table 3-3, Figure 3-4). However, the difference between the highest value of 9.1 and the lowest value of 7.9 is actually quite small and probably not significant. The changes in conductivity, however, are very distinct between the upstream and downstream stations (Table 3-3, Figure 3-4). At Station 1 conductivity was 150 μmhos/cm. While this value increases slightly at Stations 1a and 2, it jumped to 290 μmhos/cm at Station 3 and essentially stayed at that level at the remaining stations. Measured field pH values decreased from Stations 1 to 2, but increased again in the downstream stations (Table 3-3, Figure 3-4).

TABLE 3-6

PERCENTAGE COMPOSITION OF ALGAL SPECIES WITHIN THE DIVISIONS

Taxa	Station 1	1a	2	3	5	6	7
DIVISION BACILLARIOPHYTA							
Achnanthes affinis	<1[1]	10	35	9	4	4	1
A. lanceolata var. dubia	1		17	1		1	
A. lanceolata var. lanceolata		2					
A. linearis		1		1			5
A. microcephala	8	11		32	15	7	
A. minutissima	44	35		12	42		
Cocconeis placentula	<1		8	1	1	2	
Cyclotella meneghiniana					1		
Cymbella minuta var. silesiaca	<1	3			1	3	
Diatoma vulgare				2	2	2	
Eunotia sp.		1					
Fragilaria leptostauron						<1	
F. vaucheriae	28	25	15	31	18	1	55
Gomphonema angustatum							2
G. olivaceum							7
G. parvulum						2	
G. subclavatum var. commutatum						1	
Hannaea arcus	1				<1		
Navicula atomus	<1						
N. canalis						<1	
N. cryptocephala var. veneta	<1			2	3	5	
N. heufleri var. heufleri						2	1
N. lanceolata					<1		
N. minima	<1						
N. minuscula	1			<1		1	
N. notha					<1	2	
N. pelliculosa					<1		
N. secreta var. apiculata		7		<1		7	1
Nitzschia sp.	1						
N. communis		1		2			
N. dissipata var. dissipata						9	4

TABLE 3-6 (CONTINUED)

Taxa	Station						
	1	1a	2	3	5	6	7
N. dissipata var. ?						3	
N. fonticola							6
N. frustulum						1	
N. hantzschiana						2	<1
N. hungarica						<1	
N. inconspicua						8	
N. linearis	4	2		1	1	8	
N. microcephala						2	
N. palea	3			<1	3		1
N. paleacea				2	2	14	
N. romana						2	9
Rhoicosphenia curvata						1	
Surirella sp.					1		
S. angustata		2					
S. ovalis	<1	1					
S. ovata	7	3	25	3	5	7	7
Synedra rumpens var. *rumpens*							2
S. ulna var. *contracta*						2	
DIVISION CHLOROPHYTA							
Chlorella sp.							<1
Ulotrhix xp.							7
DIVISION CYANOPHYTA							
Lyngbya sp.					2		
L. birgei	10			10	10		
L. nana	5		60				2
L. versicolor							25

TABLE 3-6 (CONTINUED)

Taxa	Station 1	1a	2	3	5	6	7
Oscillatoria amoena		24					65
O. limosa					15		
O. nigra		53		20	2	5	5
O. sancta	35			30	65	55	
O. tenuis	25	18	30	25	6	35	
Phormidium sp.	25	4	4	10			3
P. angustissima					<1		
P. lucidum			6	5		5	
No. of Taxa	22	18	9	22	25	33	22
Ash Free Dry Weight	0.4602	1.3093	0.0011	0.2292	0.1957	0.6460	0.4061

[1] <1 = less than 1 percent.

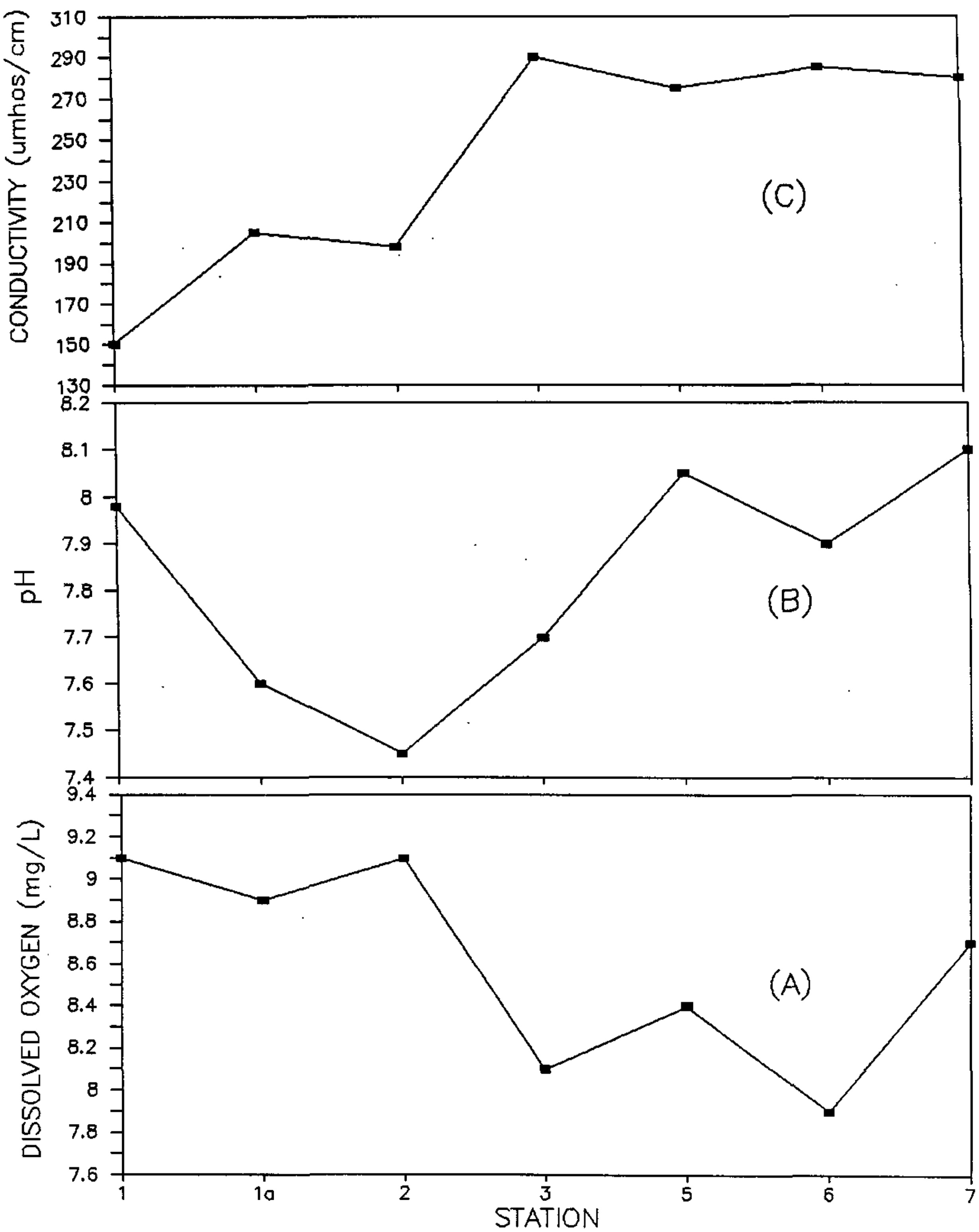

Figure 3-4. Dissolved Oxygen (A), pH (B), and Electrical Conductivity (C) Measured at Each Station.

Chemical parameters measured in the laboratory are presented in Table 3-7. Both TSS and TDS were lower at Stations 1 and 1a and then increased to a fairly constant value at the remaining stations. Both total alkalinity and chloride changed notably only at Station 2, with alkalinity decreasing to 58 mg/L and chloride increasing to 20 mg/L. The average concentrations for alkalinity and chloride at the remaining stations were 76 ($\pm$3.1) and 5.7 ($\pm$1.8), respectively.

Some metals, in both the suspended and dissolved forms, were measured at consistently low levels at all stations. Those metals include cadmium, lead, molybdenum, and barium. The concentration of suspended iron was always higher than the concentration of dissolved iron, while the reverse was true for manganese. While concentrations for most metals varied across all stations, certain values are especially noticeable. Concentrations found at Station 1 were generally lower than any other stations; this was especially true for aluminum where a concentration 0.70 mg/L suspended Al is compared to higher (approximately 1.0) concentrations at the remaining stations. A concentration of 2.50 mg/L of suspended aluminum at Station 2 was considerably higher than at the other stations. Dissolved manganese was also the highest at Station 2, with a concentration of 0.72 mg/L.

TABLE 3-7

RESULTS OF ANALYSIS OF RED RIVER WATER SAMPLES

FOR VARIOUS PARAMETERS INCLUDING DISSOLVED AND SUSPENDED METALS[1]

Station		pH (Lab)	TSS	TDS	Total Alk.[2]	Cl	Cd	Pb	Fe	Mn	Mo	Zn	Cu	Al	Ba
1	SM[3]	8.10	9.0	210	78	4.0	<.005	<.05	0.29	0.01	<.02	0.01	<.01	0.70	<.5
	DM[3]						0.005	<.05	0.05	0.15	<.02	0.04	0.02	<.5	<.5
1a	SM	7.90	8.0	172	70	3.0	<.005	<.05	0.39	0.01	<.02	0.03	0.01	0.80	<.5
	DM						0.005	<.05	0.05	0.23	<.02	0.04	0.02	<.5	<.5
2	SM	7.50	17.0	256	58	20.0	<.005	<.05	0.51	0.02	<.02	0.06	0.02	2.50	<.5
	DM						0.005	<.05	0.04	0.72	<.02	0.12	0.02	<.5	<.5
3	SM	7.40	16.0	256	77	5.0	<.005	<.05	0.54	0.02	<.02	0.07	0.02	1.80	<.5
	DM						0.005	<.05	0.09	0.54	<.02	0.07	0.02	1.00	<.5
5	SM	7.50	17.0	252	74	8.0	<.005	<.05	0.37	0.02	<.02	0.05	0.01	1.20	<.5
	DM						0.005	<.05	0.04	0.33	<.02	0.05	0.02	1.00	<.5
6	SM	7.70	10.0	243	78	7.0	<.005	<.05	0.60	0.03	<.02	0.07	0.02	1.70	<.5
	DM						0.005	<.05	0.05	0.47	<.02	0.06	0.02	1.00	<.5
7	SM	7.70	10.0	227	79	7.0	<.005	<.05	0.50	0.05	<.02	0.04	0.01	1.00	<.5
	DM						0.005	<.05	0.05	0.24	<.02	0.03	0.02	1.00	<.5

[1] All values are mg/l (ppm).

[2] Alkalinity as mg/l $CaCO_3$.

[3] For metals, SM = Suspended Metals; DM = Dissolved Metals.

4.0 DISCUSSION

4.1 Benthic Macroinvertebrates

A comparison of the data presented in this report with that collected by Pennak in previous years is difficult because of the lack of detailed data in the latter. Certain dominant taxa tabulated by Pennak (1983), such as Baetis, Brachycentrus, Hydropsyche, and Atherix were also found in this study. Pennak (1983) did report dry weight of the benthic organisms as grams/m^2. Although there was considerably variation over the study years, he found that the greatest minimum value was at Station 6, which also produced the greatest dry weight in the current study. The studies completed by the Environmental Improvement Division of the State of New Mexico were much more thorough in their analysis of the benthic data. Smolka and Jacobi (1986) reported data from several sampling sites on the Red River located from above the town of Red River to below the Red River Fish Hatchery. As in ENSR's study, there appeared to be a general shift in species composition moving from the upstream stations to the downstream stations. At their Station HRG27 (STORET designation), Hydropsyche sp. was found at a density of 1294 organisms/m^2 which is over 63 percent of the total, while at HRG22 and HRG23.3 (both of which are upstream of any ENSR station) no specimens of Hydropsyche sp. were found. Similarly, HRG27, which is located very near ENSR Station 6, had virtually the same BCI - 97.9 - as Station 6 - 99.50.

In terms of benthic community, therefore, there appears to be a definite longitudinal trend in community structure within the Red River; a trend that is supported by historical data. Part of this trend is probably due to natural and expected changes in any lotic system moving from a low order stream (headwaters) to a high order stream. For example, filter-feeding caddisflies, like Hydropsyche sp. would increase in density downstream as the concentration of organic material in the water column increases. Conversely, some mayflies and stoneflies are shredders and would tend to proportionally decrease downstream as the concentration of large allochthonous (leaves, etc.) material decreases. It is also possible that some changes in benthic community characteristics, including the apparent decrease in community quality, may be due, in part, to human influences. There does not appear, however, to be any influence from Molycorp's mining and milling operation. Station 1a, below the operation, was very similar to Station 1, which is above the operation.

4.2 Periphyton

The collection of periphyton was much more qualitative than the collection of benthos. A great deal of among-sample variation is therefore explainable simply be collection differences and selection of a site for scraping a sample. Pennak (1983) provides no species list of algae that were identified and organic matter weight is expressed as milligrams per 5-minute sampling period, making it impossible to compare data directly. What is interesting to note, however, is that the weight of periphyton samples collected by Pennak at Station 2 was typically low or the lowest of any of the stations. This corresponds to the current study where the AFDW was the lowest at Station 2.

Despite the difficulties in periphyton data comparison, it appears that the highest primary production, based upon biomass, is occurring at Station 6. Smolka and Jacobi (1986) reported increasing total phosphorus levels going downstream, with the highest levels existing just above and just below the fish hatchery. The increase were probably not due to the city of Questa since concentrations were elevated upstream as well as downstream of Questa. Nor is it likely that contributions were coming from the fish hatchery since levels of phosphorus were high above as well as below the hatchery. It is possible that nonpoint-source runoff may be contributing to the increase. The higher phosphorus levels probably contribute to higher primary production in the river, although it is not known what proportion of the total phosphorus is actually bioavailable.

4.3 Chemical Parameters

It is possible to compare some of the water chemistry information collected by ENSR to the STORET data tabulated in Smolka and Jacobi (1986). HRG27 and HRG24 on the Red River correspond closely to Stations 6 and 4, respectively. Seven metals from STORET data presented by Smolka and Jacobi (1986) are also presented in this report; those are: barium, cadmium, lead, copper, zinc, manganese, and molybdenum (Table 4-1). The STORET values are averages of several sampling dates in 1984 and 1985.

TABLE 4-1

COMPARISON OF STORET AND ENSR DATA ON SEVEN METALS[1]

Metal	STORET HRG24	Station 2	STORET HRG27	Station 6
Ba	0.1[2]	<1.0	0.1	<1.0
Cd	0.001	<0.010	0.001	<0.010
Pb	0.009	<0.1	0.01	<0.1
Cu	0.063	0.04	0.050	0.04
Zn	0.218	0.18	0.11	0.13
Mn	0.610	0.74	0.560	0.50
Moly	0.010	<0.04	0.022	<0.04

[1] STORET values are total metals; ENSR values were derived by combining suspended and dissolved forms.

[2] All concentrations are in mg/l.

With four metals, the concentration is less than the detection limit. Therefore, the ENSR values may, in fact, be as low as the STORET data. For the additional three metals, the ENSR values are near or below the STORET concentrations.

In both the STORET data and the ENSR data there is a distinct change in the chemical characteristics of the Red River in the vicinity of Station 2. Metals concentrations (e.g., aluminum) increase as do solids (both TDS and TSS). At Station 2, particularly, alkalinity and chloride decrease. The decrease in alkalinity is of particular concern since the toxicity of several metals, including cadmium, increase at lower alkalinities.

It is probable that the river, between Stations 1a and 2, is receiving nonpoint input directly from surface runoff, or as a result of groundwater seepage, which may accumulate metals during passage through soil and bedrock. Although the number of benthic and periphyton taxa was lowest at Station 2, it is not known whether the change in water chemistry contributed to this low diversity; however, the possibility of impact on the biological community does exist. Because of the high concentration of metals in the watershed, the change in water chemistry found in the Red River may be a result of natural infiltration, human-induced impacts, or a combination of both.

5.0 SUMMARY

Results of this study indicate that there is a distinct and significant change in the benthic community along the length of the Red River. This change is probably a result of natural community variation as well as changes in water chemistry that could be affecting populations. The changes do not appear to be catastrophic and probably do not affect river productivity, beyond that which would be expected under natural conditions. It is not possible, however, to determine the magnitude of any impact from changes in water chemistry. Nor is it possible to ascertain whether changes in water chemistry are due to natural watershed soil chemistry or to human activities. In general, considering dissolved oxygen, pH, conductivity, and other basic parameters, as well as some benthic indicators, the overall water quality of the Red River appears to be good.

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CPP Pinkerton®

Supervisor's Accident Investigation Report

Office:

Location Number:

Address:

Telephone:
(Include Area Code)

1. Name of Injured: Age: Sex: Soc. Sec.

   Home Address: Telephone:

2. Date of Employment: Post Held: Dept. Length of Time at This Job:

3. Type of Accident: Slip____ Fall____ Sprain____ Strain____ Lifting____ Auto____ Firearms____ Other (explain)__________

4. Place of Accident: Date/Time: Client Site? (Yes or No)

5. What happened? Based on your investigation, describe what took place:

6. If auto accident, has proper report been submitted in addition to this report? If no, explain:

7. What is the extent of the injury?

8. Has time been lost?

9. Was injured hospitalized?

10. Did injured receive prompt, proper medical care?

11. Name and address of physician and hospital:

12. Why did accident happen? (Get all the facts. Study the job, study the situation.) Be sure to answer questions: WHY - WHAT - WHERE - WHEN - WHO - HOW

13. What should be done to avoid this type of accident in the future? Which items require attention?

EQUIPMENT	CONDITION	PEOPLE	EXPLAIN:
Selection ______	Client Site ______	Improper ______	
Lack of ______	Housekeeping ______	Placement ______	
Usage ______	Weather ______	Training ______	
Maintenance ______	Situation ______	Leadership ______	

14. What have you done thus far? Take or recommend action depending on authority If client involved, what action taken? Follow up: action taken?

15. If accident was caused by hazardous or unsafe condition on client site, has the client been advised of the condition? Has the condition been corrected?

16. If not, has the client made a commitment to correct the unsafe condition?

17. How will your actions improve operations? (Remember: the purpose of accident investigation is accident prevention.)

Supervisor:______________________ Position:______________ Date of Report:______________

Reviewed by: ______________________________
Area Manager or Operations Manager (Date)

Note: All lost time injuries must be reviewed by area manager. Use additional sheets if necessary.

Form 110 (Rev. 3/88)

M-00000657

ATTACHMENT
7.4

ENSR Consulting and Engineering

Molycorp - Mining Operation Site Assessment

June 27, 1994

5.0 Local Communities

5.1 Background Information

The Molycorp/Questa Mine operation is located in Taos County. The communities of Questa, Taos, and Cerro are located within 30 miles of the Molycorp operation. The county, as well as this entire region, was historically dependent on small scale agriculture as its chief source of income. However, with a national movement toward large scale agricultural facilities and with the advent of large-scale mechanized farming techniques, this sector has decreased its contribution to the county economy. Tourist-related business is currently the major economic activity and source of revenue in Taos County.

Population.

The population of Taos County is growing at an annual rate of approximately 2 percent. The 1990 Census estimated Taos County population at 23,118, an 18.8 percent increase over the 1980 population count (Taos County Economic Development Corporation [TCEDC] 1994). The most recent available population estimate is for 1992 when the population was 24,228 (Brook 1994). This represents a 4.8 percent increase over the 1990 census count (Table 1). Of the total population, approximately 25 percent reside in or near the towns of Taos and Questa (TCEDC 1994).

Economy and Employment.

The most recently available estimates indicate that county employment numbers approximately 8,747 persons. The county has historically had a high unemployment rate, fluctuating between 15 and 25 percent (TCEDC, 1994). Employment in Taos County is dominated by the service and retail trade sectors (See Table 2 and Figure 1). Together these sectors account for 64 percent of employed persons over 16 years of age (Brook 1994). As tourist-related activities contribute to the *service sector* in Taos County, many of the available jobs are service related in such industries as lodging, food, and entertainment. The government sector accounts for approximately 18 percent of employed persons. Taos County employment is largely wage and salary work, however approximately 17 percent consists of self-employed persons (TCEDC, 1994). The 1991 per capita personal income was $11,063 and has been growing at an average annual rate of 5.5 percent since 1986 (Brook 1994).

Fiscal resources for Taos County are largely dependent on property tax revenue. Taxable valuation of county properties has increase by 18 percent over a three year period beginning in 1991. The 1993 taxable valuation was $308,111,937. Commercial properties are assessed a mill levy of $20 per $1000 of value, while residential properties are assessed $11 per $1000 of value (Nichols 1994).

According to the 1990 Census, there were 12,020 housing units in Taos County. Of these, approximately 8,752 are occupied by both renters and owners. There were approximately 3,268 vacant units. Of these, 371 were rental units and 137 were units for sale. Temporary housing, such as hotel and motel units, vary in availability according to seasonal tourist fluctuations. The average vacancy rate, however, is listed as 14.5 percent in Taos County (TCEDC 1994).

Taos County and its associated municipalities provide an array of public and private services and facilities. These include health care, law enforcement, education, recreation, water and wastewater services, gas and electric (USDI BLM 1988).

Table 1

Recent Population Trends
Taos County

	1980 (Census)	1990 (Census)	1991 (Estimated)	1992 (Estimated)
Taos County	19,456	23,118	23,694	24,228
Percent Change	--	18.8	2.5	2.3
Town of Taos	5,369	4,065	--	--
Questa Village	--	1,699	--	--

Source: Brook, K. - State Data Center 1994.

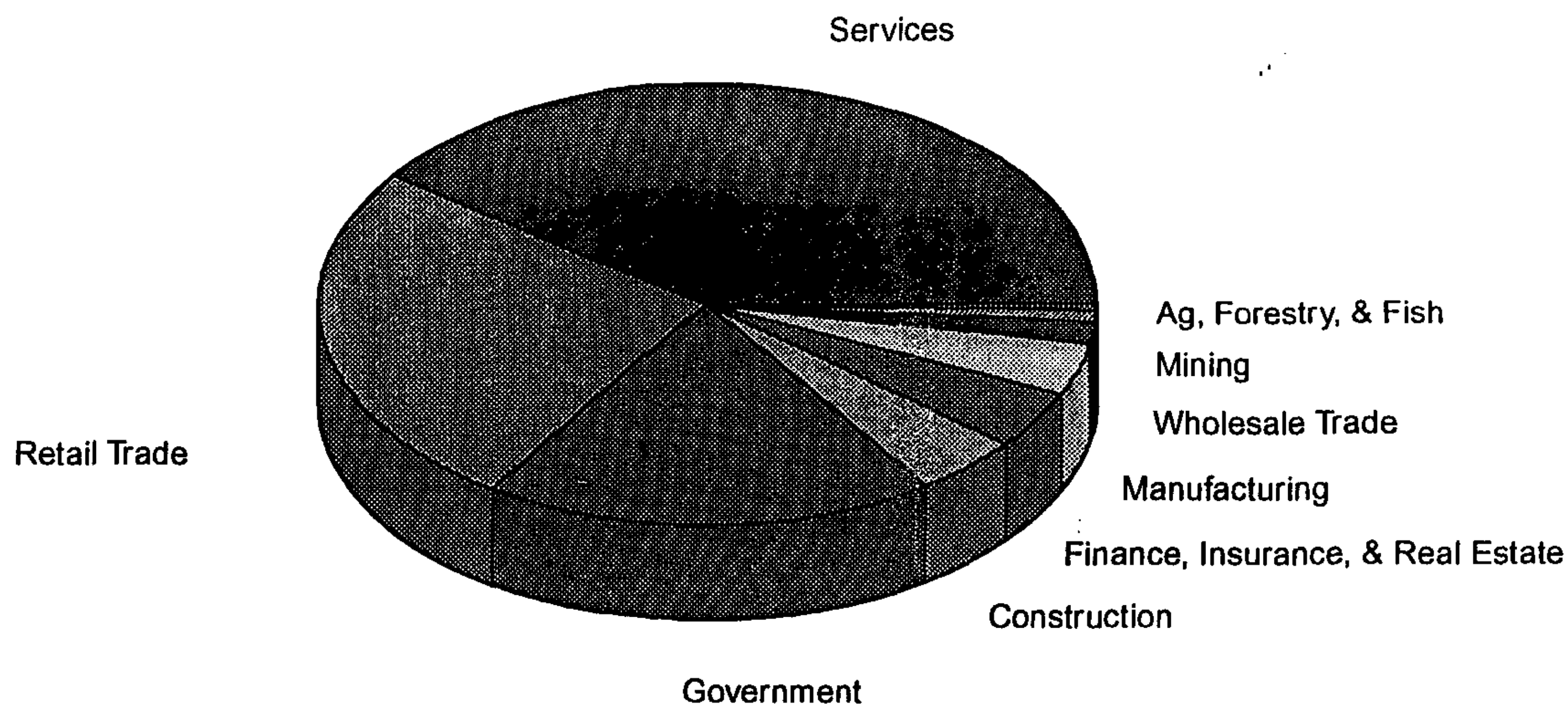
Table 2

Employment by Sector (1993)

Agriculture, Forestry, and Fish	41
Mining	77
Construction	375
Manufacturing	328
Transportation, Communication, and Utilities	256
Wholesale Trade	139
Retail Trade	2,207
Finance, Insurance, and Real Estate	358
Services	3,379
Government	1,587
Total	8,747

Source: Brook, K. - State Data Center 1994.

Figure 1
Employment by Sector (1993)



M-0000663

5.2 Effects of Current Mining Operations

Mining at the current site began in the 1920s. At its peak in 1985, the Molycorp/Questa Mine operation employed over 800 persons. Due to the drop in world market prices for molybdenum, the mine scaled down operations and employment from 1986 to 1992. In 1992, mining operations were placed on stand-by status (Shoemaker 1994).

The current activities at the Molycorp/Questa Mine operation consist of administrative services, maintenance, and environmental and reclamation work. Current operations employ approximately 19 persons. Should mining operations eventually resume, employment would increase to at least 220 persons (minimum operating staff) with the potential full-operational staff possibly reaching 800 persons.

Population.

Current mine operations have had no impact on the County's population or demographics. If operations at the mine are resumed, an increase in County population of not more than 1 to 3 percent (depending on actual hires) can be expected. This potential population increase would be reduced to the extent that Molycorp is able to hire local residents to fill job openings.

Economy and Employment.

Mining employment in Taos County in 1993 consisted of 77 jobs, accounting for approximately one percent of total employment. Current operations at the Molycorp/Questa mine provide approximately 19 of those jobs. If operations are eventually resumed, an increase to 220 employees at the Molycorp mine would increase mining employment to 4 percent of total employment in the county and an increase to 800 employees would increase mining sector employment to 12 percent of total county employment. Resumption of mining at the Molycorp/Questa mine would serve to decrease unemployment in Taos County. The amount of this decrease would depend on the necessary skills required by mine employers and the availability of these skills in the local population.

Current average annual wage for mining staff at the Molycorp mine is approximately $510,000 plus benefits, more than twice the income per capita for the county. The current average monthly payroll (summer months) is approximately $74,000. These wages are largely spent on local goods and services in those communities where mine employees reside (primarily Questa and Taos). If operations are eventually resumed the monthly payroll could increase to as much as $1.83 million (average monthly payroll in 1985) (Santistevan 1994).

Current operating expenditures are approximately $4,000,000 annually. These expenditures are made to local, state, and out-of-state suppliers and contractors. Depending on the goods and services purchased, these expenditures generate sales and use taxes. In 1993, such expenditures generated approximately $65,000 in sales and gross receipts taxes. These taxes are paid to federal, state, and local governments. If the mine eventually resumes operation, expenditures could increase to as much as $68 million annually (1985 total expenditures), dramatically increasing potential tax revenues (Santistevan 1994).

Current mine operations generated approximately $27,000 in county property taxes in 1993. These taxes are currently paid on the depreciated value of equipment. If operations resume, taxes would be paid on equipment and mining activity. In 1985, at full operation, Molycorp paid over $400,000 in county property taxes (Santistevan 1994).

Community Services.

Current operations have little effect on local community services. If mining operations are eventually resumed, there would be some in-migration of persons due to mining employment and skill requirements. Given the current level of services and the availability of housing, adverse impacts to community services are not anticipated.

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6.0 Wildlife and Wildlife Habitat

6.1 Background Information

The Molycorp/Questa Mine operation includes the mine and mill facilities, tailings slurry pipelines, and tailings ponds. The mine and mill are located in mixed conifer forest on the western slope of the Taos Range of the Sangre de Cristo Mountains approximately 5 miles east of the Village of Questa. The tailings slurry pipelines run from the milling operation along riparian habitats associated with the Red River from the mill to the tailings ponds, and the tailings ponds are located adjacent to sagebrush and grassland habitats approximately 1/2 mile to the west of Questa. Figure 1 provides a general location map of the Molycorp operation. The general area of the mining operation ranges from over 10,000 feet in elevation at portions of the mine to less than 8,000 feet at the tailings facilities. A variety of mammals, birds, reptiles and amphibians are associated with the mining operation area.

Mammals.

Game animals or furbearers that may typically use the mine area or adjacent habitats include mule deer, elk, black bear, mountain lion, bobcat, coyote, gray fox, raccoon, ringtail, and cottontail.

Mule deer occur year-round throughout most of the operations area with populations considered to be stable. Annual aerial survey data collected by the New Mexico Game and Fish Department (NMGF) showed observations in Hunt Unit 53 of 188, 226, and 194 mule deer during the winter census of 1992, 1993, and 1994, respectively. Hunt Unit 53 includes the Molycorp Mine and much of the forest lands in the Taos Range. The State of New Mexico has not mapped any specific big game ranges in the mining operations area (Catanach 1994) nor has the U.S. Forest Service, Carson National Forest (USFS) according to Long (1994). Both agencies report that mule deer regularly use the mine site and adjacent habitats with winter, spring, fall use of the south-facing slopes near the mine. Mule deer may also use habitats near, and particularly west of, the tailings ponds.

Elk are also present in the mine area. USFS biologists and Molycorp personnel report that elk are regularly seen on the mine property (Kuykendall 1994). Annual aerial survey data collected by NMGF showed observations in Hunt Unit 53 of 96, 116, and 107 elk during the winter census of 1992, 1993, and 1994, respectively. No specific elk ranges have been mapped by either NMGF or USFS (Catanach 1994, Long 1994), but use patterns generally parallel mule deer with elk more tolerant of greater snow depth.

Bobcat, coyote, gray fox, raccoon, and ringtail are all found within the mine operations area. The coyote is thought to be the most common of these and is found throughout the area, and the raccoon would be expected along the Red River. Black bear and mountain lion occur in limited numbers in the mountainous areas near the mine and have also been reported just west of the tailings facilities near Guadalupe Mountain (USDI BLM 1987).

Numerous small mammals may also inhabit the mine area. Productivity of these species varies from year to year. Small, non-game mammals on or near the mine or tailings area include such species as the white-tailed jackrabbit, Ord's kangaroo rat, deer mouse, and least chipmunk.

<u>Birds.</u>

The high elevation mixed conifers, ponderosa pine woodlands, riparian systems, and sagebrush/grasslands support a broad diversity of both nesting and migrant bird species. Kennedy and Stahlecker (1986) recorded 133 avian species in studies conducted near the tailings facilities. Additional bird species occur in the mine area (USDI BLM 1988). Upland game birds include Merriam's turkey, blue grouse, scaled quail, and mourning dove. Waterfowl and shorebirds use the Red River as well as the tailings impoundment with typical nesting species including the mallard and common merganser. Raptors are found throughout the area and are represented by species such as the red-tailed hawk, American kestrel, great-horned owl, and saw-whet owl. Threatened or endangered species are discussed later.

Fisheries.

Fisheries resources in the project area are found in the Red River. The Red River lies in the Rio Grande watershed in northern New Mexico with headwaters in the Sangre de Cristo Mountains at an elevation of 12,500 feet. The East and Middle forks of the Red River merge to form the main channel approximately 6 miles upstream of the town of Red River at an elevation of 9,400 feet. From that point, the river flows in a westerly direction for approximately 27 miles, eventually emptying into the Rio Grande at an elevation of 6,500 feet. The river flows adjacent to the Molycorp Mine and Mill approximately 6 miles below the town of Red River and 21 miles above its confluence with the Rio Grande. Figure 1 shows that the Red River canyon forms the southern boundary of the Molycorp Mine and Mill complex. The drainage area of the Red River is approximately 190 square miles with an average annual discharge of 34.5 cubic feet per second (cfs) (Smolka and Jacobi 1986).

There are reproducing populations of cutthroat, brook, and brown trout inhabiting the river's upper reaches above the town of Red River. A reproducing brown trout population provides a high quality fishery in the rivers lower reach. Rainbow trout are stocked annually in the middle reaches of the River by the Town of Red River and by the New Mexico Game and Fish Department (Smolka and Jacobi 1986). The middle reaches of the river between the towns of Red River and Questa have been characterized as having poor potential for trout reproduction; this is thought to be related to both a paucity of available macroinvertebrates for trout prey and to limited availability spawning substrates (Smolka and Tague 1987).

Effects of Current Mining Operations

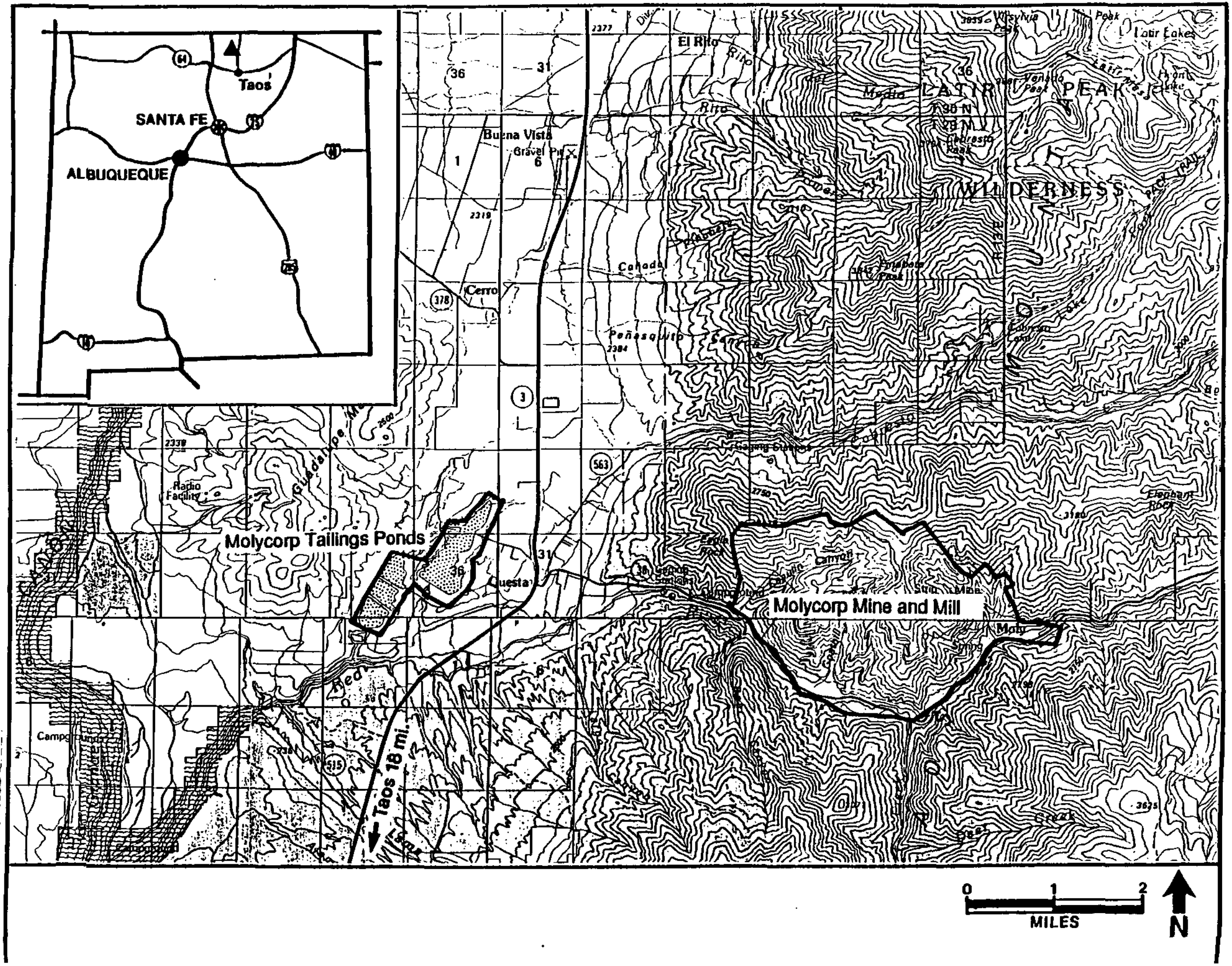
Fisheries resources in the Red River are not being affected by the current mining operations. Limitations in fisheries habitat in the middle reaches of the river are thought to be due to natural processes acting on the extensive hydrothermal scarring occurring along this segment of the river, some of which were incorporated into the historic surface mining area of the Molycorp Mine. Observation made during a thunderstorm runoff event by Smolka and Tague (1987) show that flooding of these geothermal scars and other erodible soils substantially increase turbidity and the presence of many minerals and metals while lowering the pH from slightly basic to very acidic (8.1 to 3.8) This may result in periodic toxicity, and downstream, these materials may precipitate out to armor the channel and limit spawning substrate (see Water Resources Section).

Amphibians and Reptiles.

Amphibians and reptiles found in the area include the western spadefoot toad, leopard frog, collard lizard, great plains skink, bullsnake, and prairie rattlesnake.

Threatened or Endangered Species.

Threatened or endangered species associated with the mine area include the bald eagle, American peregrine falcon, and whooping crane. The bald eagle is both federal and state-listed as endangered. Wintering bald eagles are known from the upper Rio Grande Gorge to the west of the tailings ponds and may occasionally use Red River habitats as well. Likewise, the peregrine falcon and whooping crane are also both federal and state-listed. An active peregrine aerie is located within the region. The whooping crane may potentially pass through the project area during migration but use of habitats on or adjacent to the mining operation is not expected.



Taos
SANTA FE
ALBUQUEQUE
El Rito
Buena Vista
Gravel Pit
Cerro
LATIR PEAK
WILDERNESS
Radio Facility
Molycorp Tailings Ponds
Questa
Molycorp Mine and Mill
Campground
Taos 18 mi.
0
1
2
MILES
N

6.2 Effects of Current Mining Operations

Current mining operations are not substantially affecting wildlife or wildlife habitat. The current activities at the Molycorp/Questa Mine operation consist of administrative services, maintenance, and environmental and reclamation work and employs approximately 19 persons.

No additional surface disturbance to the mine is occurring at this time. Physical work on the mine property consists primarily of road maintenance, drainage control, and limited reclamation plantings in conjunction with revegetation studies. Natural revegetation is occurring slowly on certain microclimates within the historic mining area. Wildlife regularly use the mine and adjacent habitats. There have been numerous observations of elk and deer on the mine and in the area surrounding the Administration Building (Shoemaker 1994). A site visit during April 1994 showed established big game trails across portions of the mine and evidence of substantial big game use in undisturbed habitats nearby.

Because the mine and mill are not operational, there is currently no concern over a break or leak in the tailings lines along the Red River canyon. Molycorp plans to use the lines during the summer months to provide water to the tailings ponds for dust control as necessary.

The tailings ponds west of Questa are approximately 85 percent capped during this closure period to control dust. A portion of this area has also been revegetated to further aid in the control of wind-generated dust. Water is regularly applied to the uncapped portion of the ponds as needed. There is limited bird and other wildlife use of the tailings ponds area.

6.3 References

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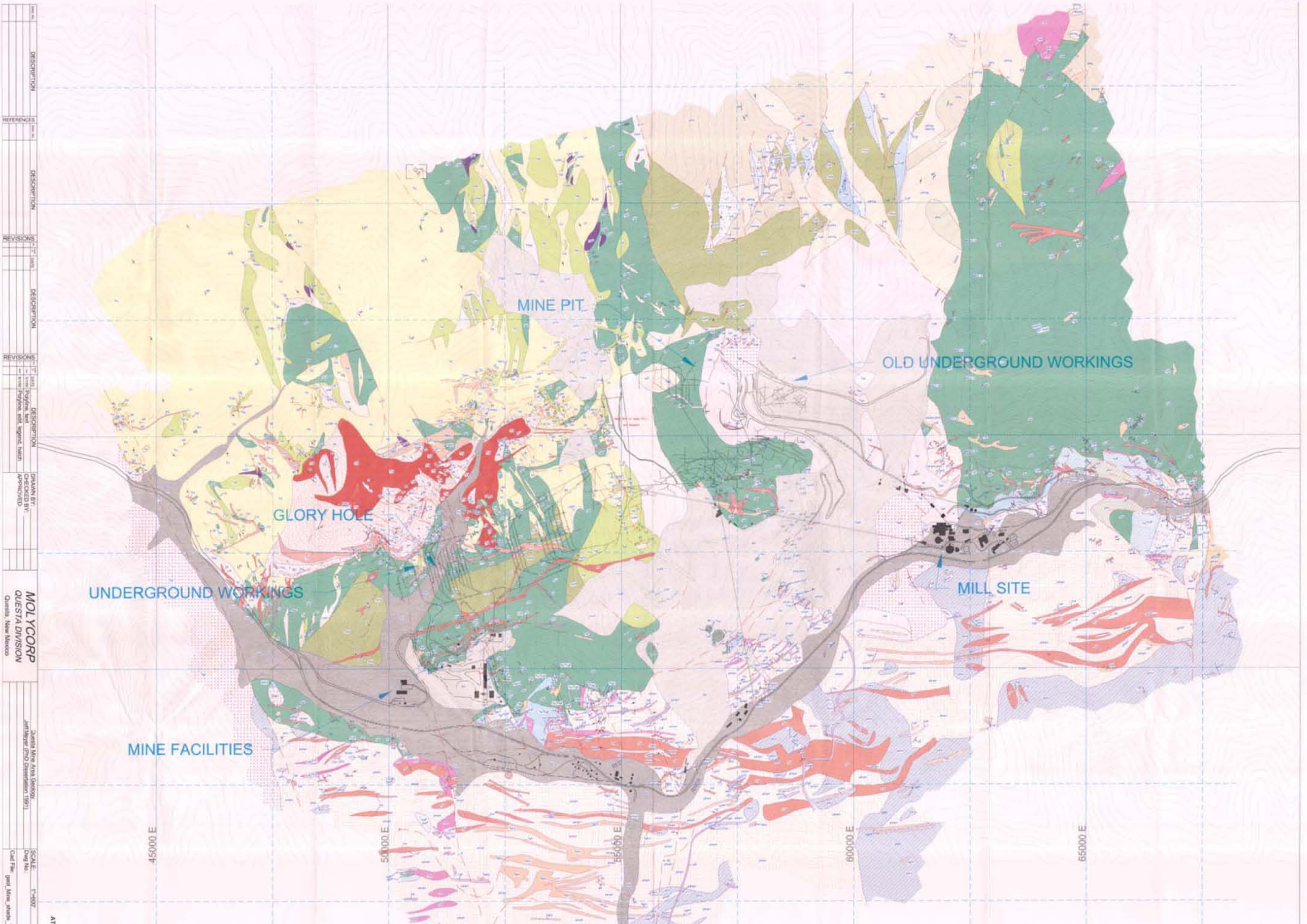
MINE PIT
OLD UNDERGROUND WORKINGS
GLORY HOLE
UNDERGROUND WORKINGS
MILL SITE
MINE FACILITIES
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50000 E
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65000 E
MOLYCORP
QUESTA DIVISION
Questa, New Mexico
Questa Mine Area Geology
Jeff Meyer (PhD Dissertation 1991)
SCALE: 1"=800'
ATTACHMENT 7.5
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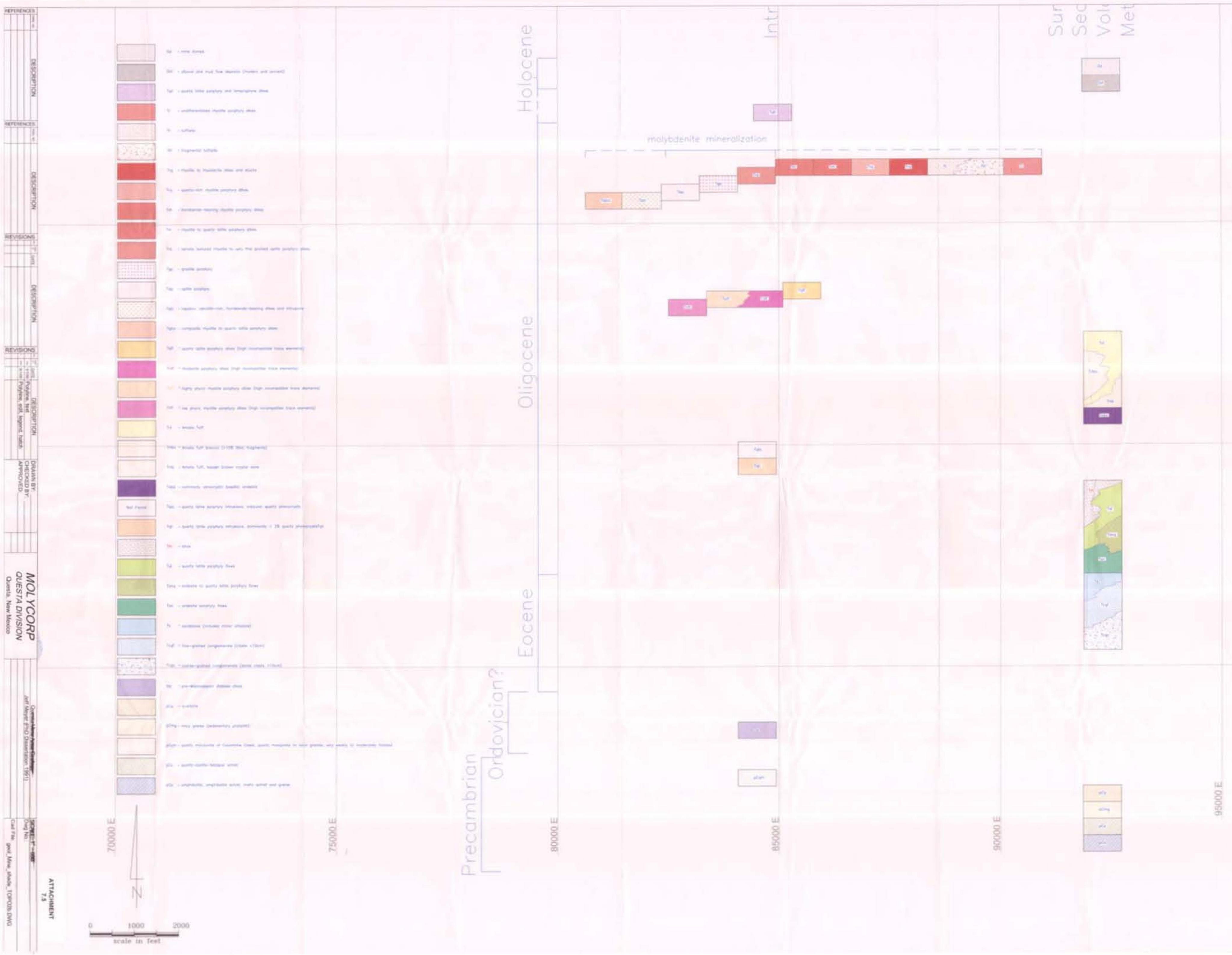

MOLYCORP
QUESTA DIVISION
Questa, New Mexico
Jeff Meyer (PhD Dissertation, 1991)
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ATTACHMENT
7.5
Holocene
Oligocene
Eocene
Ordovician?
Precambrian
molybdenite mineralization
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MOLYCORP
QUESTA DIVISION
Questa, New Mexico

Red River Region Geologic Map
J. Meyer PhD Dissertation—Plate 1

SCALE: 1"=2000'
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ATTACHMENT 7.5

ATTACHMENT
7.6

AQUATIC ECOSYSTEMS OF RED RIVER, NEW MEXICO, IN OCTOBER, 1976
A COMPARISON WITH CONDITIONS IN OCTOBER, 1971

by

Robert W. Pennak

Thorne Ecological Institute

November, 1976

M-00000678

AQUATIC ECOSYSTEMS OF RED RIVER

INTRODUCTION

In 1971 the writer worked on the aquatic ecology of the Red River, New Mexico, with special reference to the effects of a large settling pond outflow tributary and with special reference to baseline conditions at that time. During the past five years the Molybdenum Corporation of America has continued its operations in the Questa area. The settling pond has been deepened, and since April 9, 1975, there have been at least eight instances of broken and leaking pipes which allowed the finely particulate mill waste to enter the Red River below the mining and processing area.

SCOPE, METHODS, AND MATERIALS

In October, 1976, the writer did a repeat field study in order to determine what effects these incidents have had on the Red River aquatic ecosystem. For the most part, the 1976 methods and data duplicated those of 1971. In addition to the five field stations covered in 1971, however, a sixth station (just above Goat Hill Campground) was included as an additional check because most of the pipeline leaks occurred very near this point.

---

*Pennak, R. W. 1972. Limnological conditions in the Red River, New Mexico, during the open season of 1971, with special reference to the effects of a large settling pond tributary. 28 pp. Rocky Mountain Center on Environment, Denver, Colorado.

Thus, the six stations are:

East of Questa

Station 1 - Red River above the eastern Molycorp property line.

Station 1A - Red River just above Goat Hill Campground (new).

Station 2 - Red River just above Eagle Rock Campground.

West of Questa

Station 3 - Red River 50 m above the Pope Creek inlet.

Station 4 - Pope Creek 50 m above its entrance into Red River. This is the settling pond effluent.

Station 5 - Red River 200 m above the State Fish Hatchery

RESULTS AND DISCUSSION

Detailed results of the physical conditions are shown in Table 1. Temperatures in the two years were remarkably similar; the temperature-controlled biotic conditions were nearly identical for both sampling periods.

Turbidity, however, was quite another matter. In 1971 all stations except #1 had moderate to extreme turbidity, but in 1976 turbidity was negligible at all stations.

Suspended organic matter was much lower in 1976 than in 1971. These figures are all within "normal" expectations, and so long as suspended organic matter remains below 30 or 40 mg per liter there is no measurable biological effects.

As might be expected, the two years differed widely in their suspended loads of inorganic matter. In 1976 there were negligible quantities at all stations, but in 1971 the load ranged from heavy at Station 2 to light downstream at Station 5 (the result of a burst tailings pipe above Station 2 on the previous day).

Table 1. Physical Conditions.

Station	Temperature 1971	Temperature 1976	Turbidity 1971	Turbidity 1976	Mg per liter Suspended Organic Matter 1971	Mg per liter Suspended Organic Matter 1976	Mg per liter Suspended Inorganic Matter 1971	Mg per liter Suspended Inorganic Matter 1976
1	11.0	10.8	tr	light	5.4		28.9	7.4
1A		10.0		light		all less than 0.2		6.4
2	10.2	9.8	extreme*	light	5.0		150.4*	11.7
3	7.0	8.0	extreme*	light	8.4		81.6	4.8
4	11.2	12.0	60	tr	7.4		83.3	2.2
5	9.8	10.6	60	light	5.0		21.3	4.7

* - Burst tailings pipe one mile below plant grossly polluted the Red River the previous afternoon.

In comparing the stream substrates in the two years, there was much less fine (compacted) silt between pieces of rubble in 1976 than in 1971. In 1976 most of the silt was confined to a strip of bottom about 1 to 2 m wide along each shore at stations 1A, 2, and 3. In time, this residual silt should slowly disappear by washing downstream.

Chemical Conditions

Detailed results of the chemical conditions are shown in Table 2. With few exceptions, chemical conditions were similar for the two sampling periods. Dissolved oxygen and free CO_2 were always near saturation. Bound CO_2, pH, dissolved organic matter, and dissolved inorganic matter were closely parallel. The only important exception was the dissolved inorganic matter determination of Pope Creek water where the residue was 1176.1 mg per liter in 1976. This is roughly nine times as high as the 1971 figure,

Table 2. Chemical Conditions

Station	Dissolved oxygen		Free CO_2		Bound CO_2		pH		Dissolved organic matter		Dissolved inorganic matter	
	1971	1976	1971	1976	1971	1976	1971	1976	1971	1976	1971	1976
1	104.0	102.2	1.7	1.9	39.0	32.9	8.1	7.7	35.8	37.4	89.8	98.9
1A		108.5		2.0		34.6		7.7		47.6		138.0
2	109.6	101.7	2.0	2.7	37.0	31.0	7.7	7.5		42.7		114.0
3	107.7	101.0	2.5	2.3	42.0	42.3	7.6	7.6		57.9		165.2
4	102.2	103.7	2.5	2.4	31.0	25.6	7.7	7.7		132.6		1176.1
5	111.6	112.2	2.4	2.0	38.5	40.0	8.1	7.7	71.9	92.8	288.3	371.4

and the question remains which ion(s) are contributing to this total. Undoubtedly, much of the 132.6 mg per liter of dissolved organic matter for this sample represents loss of additional inorganic materials during ignition of the sample. Because of dilution with Red River water, the lowermost station (#5) had only 29% more dissolved inorganic material in 1976 than in 1971. Based on what is known, this increase has had no biological impact (other than increasing the productivity of Station 5).

Bottom Fauna

Detailed results of the bottom fauna conditions are shown in Table 3. In general, mayflies, especially Rhithrogena, are an indicator of good water quality, and it should be pointed out that this genus as well as the others were considerably more abundant in 1976 than in 1971.

Caddis larvae show a classical situation. Note that Arctopsyche essentially "replaced" Hydropsyche. Although both of these genera are common in the western mountain and foothills streams, Arctopsyche ordinarily is found in cleaner water than Hydropsyche. Thus, we have here a biological indicator of "cleaner" water in 1976 than in 1971.

Stonefly nymphs were nearly always more abundant in 1976 than in 1971, with the same species being found in both years. No stonefly nymphs were found in Pope Creek in either year, and very few were found at stations 3 and 5. This situation is difficult to explain, except to say that there are many unpolluted areas in western mountain streams from which stonefly nymphs are also unaccountably absent. It is possible that there is some unknown biotic or chemical factor responsible for this situation.

In general, the Red River area is characterized by relatively few species (low species diversity). In the eastern states, this situation

Table 3. Bottom fauna composition in the Red River, October 8-9, 1971 and October 5-6, 1976. Ephemeroptera (mayfly) nymphs per square meter.

Station	Rhithrogena		Ephemerella doddsi		Ephemerella		Baetis spp.		small spp.	
	1971	1976	1971	1976	1971	1976	1971	1976	1971	1976
1	0	193.5	0	6.5	4.2	43.0	8.4	17.2	0	8.6
1A	-	227.9	-	4.3	-	36.6	-	161.3	-	0
2	8.4	83.9	0	0	16.8	19.4	63.0	4.3	0	2.2
3	16.8	51.6	0	0	4.2	0	46.4	90.3	0	4.3
4	0	0	0	0	0	0	0	4.3	0	0
5	0	12.9	0	0	0	129.0	0	17.2	0	0

Table 3. (continued). Data for Trichoptera (caddis) larvae.

Station	Brachycentrus americanus		Hydropsyche		Arctopsyche		Rhyacophila	
	1971	1976	1971	1976	1971	1976	1971	1976
1	8.4	15.1	0	0	8.4	236.5	0	0
1A	-	0	-	0	-	249.4	-	0
2	46.4	6.5	0	0	0	15.1	0	2.2
3	54.6	163.4	4.2	0	4.2	322.5	0	8.6
4	0	0	92.4	0	0	55.9	0	0
5	75.6	77.4	294.0	0	0	223.6	0	0

Table 3 (continued). Data for Plecoptera (stonefly) nymphs.

Station	Pteronarcella		Pteronarcella		Arcynopteryx		small spp.	
	1971	1976	1971	1976	1971	1976	1971	1976
1	0	38.7	0	12.9	0	0	0	0
1A	-	60.2	-	17.2	-	2.2	-	2.2
2	8.4	19.4	0	10.8	2.1	2.2	0	2.2
3	14.7	4.3	0	0	0	0	0	17.2
4	0	0	0	0	0	0	0	0
5	0	17.2	0	0	0	0	0	0

would be cause for alarm and an indication of (light) pollution. In the West, however, we commonly find low species diversity, even in the most pristine mountain streams*.

Table 4 is a summary of the density of the bottom fauna in the two years, taken group by group. Almost every pair of 1971-1976 figures shows an increase in density in the latter year, and for this reason it is obvious that the data are highly significant, even without statistical treatment. The "Diptera" data are not broken down by genus. It includes a few blackfly larvae and many different kinds of chironomid larvae. Similarly, the "miscellaneous" column includes a variety of small invertebrates such as planarians, beetle larvae, hydracarina, etc. Neither the Diptera nor the miscellaneous groups show anything significant in the way of population trends.

Table 5 is a summary of the standing crop for the October samples at all six stations for the two years. In terms of organisms per square meter, there has been a remarkable increase at all stations by 1976. In terms of grams per square meter, stations 2 and 5 show decreases, but these are not especially significant decreases since they involve differences of only about 50%, and such variations may be found regularly in random sampling.

Molycorp provided the writer with a small amount of Red River bottom fauna data gathered by Cuplin and Herkenhoff of the Bureau of Land Management. Their sampling was done at the Goat Hill Campground on March 26, 1976 and at what is equivalent to this study's Station 5 on March 26 and on June 30, 1976. These data were taken during a completely different time of the year, and

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*Pennak, R. W. 1977 (in press). Trophic variables in Rocky Mountain trout streams. Arch. Hydrobiol. (about 20 pages).

Table 4. Summary of density of bottom fauna, organisms per square meter.

	Ephemeroptera		Trichoptera		Plecoptera		Diptera		miscellaneous	
Station	1971	1976	1971	1976	1971	1976	1971	1976	1971	1976
1	12.6	268.8	16.8	251.6	0	41.6	0	0	0	0
1A	-	430.1	-	294.4	-	81.8	-	2.2	-	0
2	88.2	109.8	48.5	23.8	10.5	34.6	2.1	0	0	2.2
3	67.4	156.2	63.0	492.5	16.8	21.5	0	60.2	0	34.4
4	4.2	4.3	92.4	55.9	0	0	50.4	120.4	0	21.5
5	67.2	159.1	369.6	301.0	8.4	17.2	33.6	81.7	0	73.1

they cannot possibly be compared with this study's October data because of the seasonal variations in abundance of essentially every bottom fauna group found in the Red River. One comparison is possible, however, with the original 1971 report. On June 24, 1971 at Station 5 the original study found a standing crop of 478.8 organisms per square meter. Cuplin and Herkenhoff found 215.2 organisms per square meter on June 30, 1976. It is difficult to say whether these two figures have any statistical significance.

Table 5. Summary of standing crop (biomass).

	Organisms per sq. meter		Grams per sq. meter	
Station	1971	1976	1971	1976
1	29.4	562.0	0.8	6.0
1A	-	763.5	-	6.5
2	149.3	170.4	3.6	1.4
3	147.2	764.8	2.1	6.6
4	147.0	202.1	2.9	3.3
5	478.8	632.1	10.9	5.8

It is especially notable that the bottom fauna community of the Red River has persisted and maintained itself in spite of eight instances of tailings pollution below the mine caused by cracked tailings pipes between April 9, 1975 and June 26, 1976*. Even allowing for "normal" population variations from time to time, the data, taken collectively, for the six stations in Tables III, IV, and V show a richer population than was found in October five years ago. The Red River now compares well with other mid-elevation trout streams in the Rocky Mountain area**.

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*Letter from Obby Davidson, July, 1976

**Pennak, 1977, op cit.

Lithophyton

The microscopic composition of the lithophyton (periphyton) was essentially the same for both years at five stations, that is 50 to 99.5% detritus, with living material being almost entirely complicated diatom communities. At Pope Creek (Station 4), however, the situation was somewhat different. The rocks were partially covered with a growth of filamentous green algae, chiefly Cladophora, with small amounts of diatoms and Ulothrix. Only 5% of the lithophyton consisted of detritus. In 1971, the lithophyton was 20% detritus, 80% Cladophora, and a few scattered diatoms.

The special lithophyton community of Pope Creek may well be a pioneer situation that does not have an opportunity to develop into the kind of community found at the other five stations, especially since Pope Creek carries clear water and is often dry (as it was most recently between March and May, 1976).

The standing crops of organic matter in the lithophton for October in the two years are compared in Table 6. At all stations there were markedly greater quantites of this aquatic insect food material in 1976. Thus, the Red River presents no special problem in aquatic productivity. Presently there is a good standing crop of aquatic insects and an abundance of food material for these organisms. This study found no evidence that there have been "toxic" or suffocation" effects during the past months. As is the normal case after turbid heavy spring runoffs, the recovery has been rapid and complete.

Table 6. Comparison of standing crops of lithophyton in October of 1971 and 1976. Expressed as mg organic matter per five-minute sampling period.

Station	1971	1976
1	3.4	112.0
1A	-	318.8
2	12.8	38.3
3	-	494.2
4	149.8	185.8
5	39.1	360.9

Caution

Ordinarily, one would be skeptical about the statistical reliability of data taken on two days during only one month (October), but this skepticism is tempered by the fact that biotic changes from 1971 to 1976 have been consistent at all five stations.

CONCLUSIONS

The following conclusions can be offered on the basis of this study:

1. The Red River has maintained itself or has undergone rapid recovery from incidents of tailings pollution since 1971.
2. Physical and chemical features of Red River water show either no important changes, or improvement over the situation in October, 1971.
3. The bottom fauna (fish food) is now much richer than it was five years ago.
4. The production of substrate organic matter (basic food for aquatic insects) has become much richer than it was in 1971.
5. The load of dissolved inorganic matter in Pope Creek has increased notably. This may be a seasonal event, or it may be related to

ore-processing. But has no noticeable effect on the biotic community downstream from the mouth of Pope Creek.

Copy

RED RIVER, NEW MEXICO, AQUATIC ECOSYSTEMS: MARCH 1977 AS COMPARED WITH 1971 AND 1976

ATTACHMENT 7.7

Report Submitted to the

Molybdenum Corporation of America

by

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INTRODUCTION

In 1971 the writer worked on the aquatic ecology of the Red River, New Mexico, with special reference to the effects of a large settling pond outflow tributary and with special reference to baseline conditions at that time.** Since then, there have been at least nine instances of broken and leaking pipes which allowed the finely particulate mill waste to enter the Red River below the mining and processing area.

In October 1976 the writer did a repeat field study in order to determine what effects these incidents had on the Red River aquatic ecosystems.* Another serious break in the waste pipe occurred on 8 March, about one mile above our Station 1A, and in response to a request from Molycorp, the writer did a further field study (12 and 13 March) and laboratory study (14 to 24 March) in order to assess the biological effects of the accident.

** Pennak, R. W. 1971. Limnological conditions in the Red River, New Mexico, during the open season of 1971, with special reference to the effects of a large settling pond tributary. 28 pp.

* Pennak, R. W. 1976. Aquatic ecosystems of Red River, New Mexico, in October, 1976 - a comparison with conditions in October, 1971. 17 pp.

The same six sampling stations and all of the same laboratory techniques were used in the 1977 reconnaissance as were used in 1976 and 1971. Stations were as follows:

East of Questa

Station 1 - Red River above the eastern Molycorp property line.

Station 1A - Red River just above the Goat Hill Campground.

Station 2 - Red River just above Eagle Rock Campground.

West of Questa

Station 3 - Red River 50 m above the Pope Creek inlet.

Station 4 - Pope Creek 50 m above its entrance into Red River. This is the settling pond effluent.

Station 5 - Red River 200 m above the State Fish Hatchery.

In order to make our comparisons as significant as possible, we are using data taken on the following dates:

17 May 1971

8-9 Oct 1971

5-6 Oct 1976

12-13 Mar 1977

Thus we can compare the spring 1977 data with the spring 1971 data, and we can also compare the spring 1977 data with the only 1976 date (5-6 Oct) plus the parallel October data for 1971.

RESULTS AND DISCUSSION

Physical Conditions

Temperatures - Taken routinely and these data show nothing unusual.

Station	May 1971	Oct 1971	Oct 1976	Mar 1977
1	5.5	11.0	10.8	2.0
1A			10.0	3.8
2	6.0	10.2	9.8	5.0
3	12.5	7.0	8.0	2.7
4	14.5	11.2	12.0	2.8
5	14.7	9.8	10.6	7.8

Visual turbidity - Data for 1977 show no important residual effects of the slurry pollution four days previously. Presumably nearly all of the smallest and lightest particulates had previously been washed downstream.

Station	May 1971	Oct 1971	Oct 1976	Mar 1977
1	tr	tr	light	tr
1A			light	light
2	tr	extreme	light	light
3	tr	extreme	light	light
4	tr	60	tr	light
5	tr	60	light	tr

Gravimetric turbidity - Gravimetric determinations of suspended organic and inorganic matter are far more accurate than judgement observations of turbidity, and these data are as follows:

	Suspended organic, mg/l				Suspended inorganic, mg/l			
Station	May 1971	Oct 1971	Oct 1976	Mar 1977	May 1971	Oct 1971	Oct 1976	Mar 1977
1	0.8	5.4	all less than 0.2	all less than 0.2	3.6	29.8	7.4	9.3
1A							6.4	48.3
2		5.0				150.4*	11.7	71.2
3	17.6	8.4			17.6	81.6*	4.8	18.4
4	15.8	7.4			15.8	83.3	2.2	5.3
5	6.9	5.0			6.9	21.3	4.7	8.9

*Burst tailings pipe one mile below plant grossly polluted the stream on the previous afternoon.

All suspended organic determinations were well within the limits occurring in natural, undisturbed systems. Suspended inorganic material, however, was higher than normal at stations 1A and 2 in March, 1977. Presumably these are residual materials derived from mill waste deposited on the bottom above Station 1A. Nevertheless, both of these figures are well below readings that occur during and after heavy showers, when determinations commonly exceed 200 mg/l.

<u>Stream bed mill waste</u> - Mill waste silt accumulations were much greater on the stream bed in 1977 (four days after the pipe break) than in 1976 and 1971. At Station 1A (one mile below the broken pipe) this silt covered almost all of the bottom (rubble surfaces as well as interstices). But about 25% of the substrate was obscured by growths of filamentous algae, growing <u>on top of</u> the deposited silt; this is an incredibly rapid recovery phenomenon, to my knowledge heretofore unreported in the literature.

At Station 2 (just above Eagle Rock Campground) about 40% of the substrate was covered with tailings, the remainder being normal, clean rocks and rubble.

At stations 3, 4, and 5, west of Questa, there was little macroscopic physical evidence of tailings on the substrate.

It is our observation that only relatively coarse (heavy) tailings particles (the consistency of sand) remained on the substrate east of Questa. By a physical sorting process essentially all of the finest particles were washed downstream very quickly during and shortly after the broken waste pipe. By the same token, the 1977 spring runoff and heavy showers should soon scour the river bottom free of remaining mill waste on the substrate at stations 1A and 2.

Chemical Conditions

<u>Dissolved oxygen</u> - All determinations in March, 1977, were close to 100% saturation. This is usual in rapid streams having no organic pollutants.

<u>Free CO_2</u> - Always present in equilibrium concentrations of 2 to 3 ppm, corresponding to the partial pressure of CO_2 in air.

Bound CO_2 and hydrogen-ion concentration - All of these data are typical for medium-hard streams, with normal seasonal variations. The water becomes slightly harder as it passes from Station 1 to Station 5. This tendency holds for all flowages. The break in the pipe in March, 1977, had no effect on the water hardness or pH.

Station	ppm bound CO_2 May 1971	Oct 1971	Oct 1976	Mar 1977	pH May 1971	Oct 1971	Oct 1976	Mar 1977
1	29.0	39.0	32.0	29.7	7.5	8.1	7.7	7.5
1A			34.6	35.0			7.7	7.7
2		37.0	31.0	21.0		7.7	7.5	7.3
3	50.0	42.0	42.3	47.5	7.5	7.6	7.6	7.6
4	32.5	31.0	25.6	22.5	7.5	7.7	7.7	7.5
5	45.0	38.5	40.0	40.4	7.8	8.1	7.7	7.7

Dissolved materials - Quantities of dissolved organic matter (loss on ignition) in the Red River were generally similar and typical for all stations in the three different years we have worked in the area. The following data for dissolved inorganic matter, however, show considerable variations.

Mg/l dissolved inorganic matter

Station	May 1971	Oct 1971	Oct 1976	Mar 1977
1	11.0	89.8	98.9	116.2
1A			138.0	99.4
2			114.0	130.1
3			165.2	194.0
4			1176.1	265.0
5	26.2	288.3	371.4	455.0

Dissolved inorganic matter is largely dependent on volume of flow, - the lower the flow the greater the load, and all of the above data were derived at times of relatively low flow. Also, downstream stations generally show progressively higher loads. We cannot see that the 1977 data have any special significance. The water at Station 5 contained more dissolved materials than is usual for western mountain streams, but this is biologically advantageous. We fail to see any effect produced by the pipe break. Note, however, that Pope Creek in 1977 had a much lower salt load than in 1976.

Bottom Fauna

Before we began taking samples of the bottom fauna (fish food) on 12 and 13 March 1977, we were highly skeptical, but when we began working over the samples in the laboratory we were truly amazed at the results.

The same abundance of genera and species was found four days after the pipe break as were found in 1976 and 1971. They represent a "clean-water" assemblage, with typical dominant forms as follows:

Ephemeroptera (mayfly nymphs)
- *Ephemerella*
- *E. doddsi*
- *Rhithrogena*
- *Baetis*

Trichoptera (caddis larvae)
- *Brachycentrus*
- *Limnephilus*
- *Arctopsyche*
- *Rhyacophila*
- *Hydropsyche*

Plecoptera (stonefly nymphs)
- *Pteronarcys*
- *Isogenus*
- *Brachyptera*

Diptera (fly larvae)
- *Atherix*
- Chironomidae
- Tipulidae

Coleoptera (beetles)
- Elmidae larvae

There is no evidence that the pipe break of March 1977 "eliminated" any species.

In discussing the bottom fauna, it must be borne in mind that there are ordinarily wide season-to-season natural variations in populations, and it is only general trends that are significant, and not small differences in sets of data. Much of the species-by-species population irregularities may be avoided, however, by simply adding together all of the various organisms for each station on each of the selected four dates. Thus, the last six lines in the following Table are of greatest significance. On an overall basis, it should be pointed out that populations generally were much greater in 1976 and 1977 than on the two dates in 1971. This is probably a significant trend whose causes remain obscure. Note that Station 1 (above the Molycorp plant) had its greatest population in 1976, and than in 1977 the population was only 20% as great. This item has no relation to the pollution problem, but is shows how the density at a single station may vary from month to month. The Station 1A population (below the pipe break) was also reduced, by 74%, below the fall, 1976 population. This reduction may or may not have been the result of the pollution. At Station 2, on the other hand, (Eagle Rock Campground), the population was much higher after the pollution in 1977 than in the previous autumn. The same is true of the downstream stations 3 and 5 where the populations were about 200% greater in 1977 than in 1976. From the standpoint of the data in this brief study (four days after the pollution), there is no evidence to show that the mill waste had any serious effect on the density of the bottom fauna. (Data for Pope Creek have little bearing on the immediate problem. The populations density there is always low, but as shown in our 1971 report, the water of Pope Creek has no deleterious biological effect on the Red River, and may even have a beneficial fertilizing action.) For comparative purposes we may summarize the results for four critical sampling dates, expressed as numbers of organisms per square meter:

	Station	May 1971	Oct 1971	Oct 1976	Mar 1977
Ephemeroptera	1	50.4	12.6	268.8	537.4
	1A			430.1	103.2
	2	2.1	88.2	109.8	8.6
	3	59.9	67.4	156.2	1255.6
	4	0	4.2	4.3	0
	5	84.0	67.2	159.1	1062.0
Trichoptera	1	35.7	16.8	251.6	137.6
	1A			294.4	55.9
	2	12.6	48.5	23.8	21.5
	3	220.0	63.0	492.5	464.4
	4	2.1	92.4	55.9	8.6
	5	197.4	369.6	301.0	395.7
Plecoptera	1	0	0	41.6	64.7
	1A			81.8	34.4
	2	14.7	10.5	34.6	77.4
	3	3.2	16.8	21.5	98.9
	4	0	0	0	0
	5	12.6	8.4	17.2	167.7
Diptera	1	8.4	0	0	47.3
	1A			2.2	17.3
	2	2.1	2.1	0	4.3
	3	0	0	60.2	198.8
	4	8.4	50.4	120.4	0
	5	4.2	33.6	81.7	249.3
TOTAL	1	94.5	29.4	562.0	112.0
	1A			808.5	210.8
	2	31.5	149.3	168.2	554.7
	3	283.1	147.2	730.4	2017.7
	4	10.5	147.0	180.6	8.6
	5	298.2	478.8	559.0	1874.7

A second method of assessing productivity of trout streams is the measurement of the live weight (biomass) of the bottom animals (as contrasted with numbers), and such data are summarized below:

	Grams of organisms per square meter			
Station	May 1971	Oct 1971	Oct 1976	Mar 1977
1	1.7	0.8	6.0	1.7
1A			6.5	4.5
2	2.9	3.6	1.4	7.8
3	7.1	2.1	6.6	17.3
4	0.1	2.9	3.3	0.1
5	10.9	10.9	5.8	51.6

Note that Station 1 (the "control") had only 1.7 g/ sq m in 1977 as contrasted with 6.0 g/ sq m in 1976, and a population more comparable with that of 1971. Station 1A in 1977 was down 30% from the autumn of 1976, and in view of the data for the upstream Station 1 it is difficult to ascribe this decrease to the pollution four days previously. Stations 2, 3, and 5 showed no evidence of pollution damage in 1977. Indeed, the biomass showed almost fantastic increases over the other sets of data. I wish we had many more Rocky Mountain trout streams with the fish food productivity of stations 3 and 5 of the Red River!

Lithophyton

The layer of organic material covering rocks and pebbles of a stream substrate is known as the "lithophyton." Sometimes it is nothing more than a microscopically thin layer of bacterial sline and unicellular algae. At other times it may be masses of filamentous algae or a compact layer of algae and detritus 1 to 5 mm thick. It is important, however, as a fundamental food source for stream insects. The release of polluting toxic or suffocative materials into streams is quickly manifested by marked changes, decreases, or disappearance of the lithophyton, and it is therefore a feature which should be routinely measured in all stream and river studies. It is now known, however, that there is no direct relationship between the lithophyton biomass and the aquatic insect biomass.

The great portion of the lithophyton film ordinarily consists of bits of inorganic material which is of no biological importance. The organic (food) fraction, however, may be easily determined in the laboratory, and such data are summarized below

	Mg (dry weight) organic matter per 5-minute sampling period in the lithophyton			
Station	May 1971	Oct 1971	Oct 1976	Mar 1977
1	1.9	3.4	112.0	220.9
1A			318.8	1669.3
2	69.1	12.8	38.3	8.4
3	12.9		494.2	333.1
4	5.0	149.8	185.8	2791.4
5	4.6	39.1	360.9	7119.0

The periphyton crop at Station 1A, only one mile below the pipe break, is remarkably high. It consisted of filamentous algae growing on top of the particulate mill waste sediment in the stream. We are at a loss to explain this extremely rapid development of this micro-vegetation growth.

Station 2 had its usual sparse lithophyton. The data for all four dates at this station are "typical" for small Rocky Mountain trout streams. Stations 3, 4, and 5, on the other hand, had exceptionally dense growths of algae, and there is no evidence of pollution damage here. Undoubtedly, the 1977 spring runoff in the Red River will scour the stream bed and reduce the lithophyton at all river stations.

COMMENT

Our experience with broken mill waste pipelines along the Red River corroborates a generalization which we have evolved as the result of many years of field, consultation, class, and research work on streams:

> Single, severe instances of turbidity pollution have only a transient and temporary damaging effect on the stream bottom biota. Such occurrences are no more serious than a local severe cloudburst or a heavy spring runoff. The damage to the aquatic insect fauna is surprisingly small, and the recovery of this fauna is remarkably rapid.

SUMMARY AND CONCLUSIONS

On 12 and 13 March 1977, just four days after a major mill waste pipeline break along the Red River, we did a stream reconnaissance similar to those performed in 1971 and 1976, and involving the same field stations. Our field and laboratory conclusions are as follows:

1. Temperature, dissolved oxygen, free CO_2, visual turbidity, pH, and bound CO_2 were typical for this time of year. There were no residual effects of the broken pipeline.

2. Suspended inorganic materials, determined gravimetrically, showed higher than normal suspended loads at the first two stations (only) below the broken pipeline site. They were, however, well below spring runoff load levels.

3. At Station 1A (one mile below the pipeline break) almost all of the substrate was covered by a layer of the most coarse particles derived from the mill waste, but about 25% of the substrate was already covered with a layer of filamentous algae and some unicellular algae. At Station 2 (just above Eagle Rock Campground) about 40% of the substrate was covered with tailings, the remainder being clean rocks and rubble. At stations 3, 4, and 5 (west of Questa) there was little macroscopic evidence of tailings. Spring runoff should everywhere scour the stream bed free of tailings.

4. Quantities of dissolved inorganic matter showed no departures from the usual low-water situation in mountain streams.

5. Qualitatively, the same stream bottom insects were found in 1977 as were found in 1976 and 1971. It is a "clean-water" assemblage. No species were locally eliminated or significantly decreased.

6. At Station 1A (just above Goat Hill Campground) the number of bottom insects decreased by 74% as compared with this station in October 1976. It should also be pointed out, however, that there was a similar decrease at "control" Station 1 above the Molycorp plant. Stations 2, 3, and 5 exhibited much more dense insect populations in 1977 than in 1976.

7. Gravimetrically, the biomass results paralleled population density data.

8. Thus there is no evidence to show that the pipeline break had any harmful effects on the bottom insect fauna. Indeed, stations 2, 3, and 5 continue to be extremely high producers of trout food.

9. In general, the March 1977 data showed exceptionally high levels of organic food materials for insects on the stream bottom. Only Station 2 (just above Eagle Rock campground) had small quantities, in keeping with the normal situation in mountain streams.

10. We found no evidence to show that the mill waste had a suffocating effect on the algae of the stream substrate.

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P.O. Box 469
Questa, New Mexico 87556
Telephone: (505) 586-0212

UNOCAL 76
MOLYCORP

April 20, 1988

Ms. Susan Q. Foster
Executive Director
Thorne Ecological Institute
5370 Manhattan Circle, Suite 104
Boulder, Colorado 80303

John -
Dr. Bushnell

Dear Ms. Foster:

Per our telephone conversation earlier this month, I have enclosed copies of studies of the Red River which have been done during previous years. If your firm is able and interested in replicating this type of study, please send me an estimate of the costs associated for our consideration.

Please call me at 505-586-0212 if you have any questions or if I can furnish additional information.

Per Susan Foster CL
Thorne Ecol. not interested
in doing this study. They
sub contract this work out.

Very truly yours,

LeRoy E. Apodaca
Manager, Administrative Services

Dr. Robert C. Erickson - Ind. Consult.
303-530-1503 in Freshwater
10455 Oxford Rd. Biology & Fisheries
Longmont, Colo.
80501

M-00000708

Susan Q. Foster
Executive Director
Thorne Ecological Inst.
5370 Manhattan Circle
Suite 104
Boulder 80302

45 ppm m/l nitrate

NPDES
SPCC

M-00000709

447 1769 Dr. Thorn
443 5198 Dr. Willard

M-00000710

Copy

RED RIVER, NEW MEXICO, AQUATIC ECOSYSTEMS: OCTOBER 1977 AS COMPARED WITH OCTOBER 1971 AND OCTOBER 197

ATTACHMENT 7.8

Report submitted to the

Molybdenum Corporation of America

by

Robert W. Pennak
EPO Biology
University of Colorado
Boulder, Colo. 80309

11 November 1977

INTRODUCTION

The writer has, up to now, done one long study and two brief reconnaissance studies on the aquatic ecosystems of the Red River, New Mexico, for Molycorp*. The first emphasized the biological impact of the large settling pond at the head of Pope Creek. The two reconnaissance visits emphasized the significance of breaks in the mill waste pipelines just below the Molycorp mining operations area. The present brief report is based on observations along the river below the plant following heavy road and excavating machinery operations at streamside coupled with stream disturbances involved in the removal of streamside trees and shrubbery. We also visited our sampling sites west of Questa as further checks.

The same sampling stations and all of the same laboratory techniques were used in the present reconnaissance as were used in previous studies. Stations were as follows:

East of Questa:

Station 1 - Red River above the eastern Molycorp property line.

Station 1A - Red River just above Goat Hill Campground.

Station 2 - Red River just above Eagle Rock Campground.

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* 1972. Limnological Conditions in the Red River, New Mexico, During the Open Season of 1971, with Special Reference to the Effects of a Large Settling Pond Tributary.

1976. Aquatic Ecosystems of Red River, New Mexico, in October, 1976 - A Comparison with Conditions in October, 1971.

1977. Red River, New Mexico, Aquatic Ecosystems: March, 1977 as Compared with 1971 and 1976.

West of Questa:

Station 3 - Red River 50 m above Pope Creek inlet.

(Station 4 - Pope Creek 50 m above its effluent into the Red River. The Creek bed was dry and had obviously not carried water for a long time. We assume that the large settling pond has been deepened (and enlarged) to account for this lack of runoff.)

Station 5 - Red River 200 m above the State Fish Hatchery.

In order to make our comparison as significant as possible, we are using parallel data taken on the following dates:

8 - 9 October 1971

5 - 6 October 1976

19 - 20 October 1977

RESULTS AND DISCUSSION

Physical Conditions

Temperatures - Taken routinely, and these data show nothing unusual.

Station	Oct 1971	Oct 1976	Oct 1977
1	11.0	10.8	9.0
1A		10.0	8.6
2	10.2	9.8	8.0
3	7.0	8.0	5.8
5	9.8	10.6	9.0

Visual turbidity - Data for 1977 show no residual effects of streamside operations. Presumably the particulates had been washed downstream.

Station	Oct 1971	Oct 1976	Oct 1977
1	tr	light	tr
1A		light	tr
2	extreme	light	tr
3	extreme	light	tr
5	60 (turbidimeter)	light	tr

Gravimetric Turbidity - Gravimetric determinations of suspended organic and inorganic matter are far more accurate than turbidimetric or judgement observations, and our data are as follows:

	Suspended organic, mg/liter			Suspended inorganic, mg/liter		
Station	Oct 1971	Oct 1976	Oct 1977	Oct 1971	Oct 1976	Oct 1977
1	5.4	less than 0.2	less than 0.2	29.8	7.4	8.3
1A					6.4	9.4
2	5.0			150.4*	11.7	13.5
3	8.4			81.6*	4.8	11.8
5	5.0			21.3	4.7	5.6

*Burst tailings pipe one mile below the plant on the previous afternoon.

All suspended organic determinations were well within the limits occurring in natural, undisturbed systems. In both 1976 and 1977 suspended inorganic materials were low. As a comparison, determinations of suspended materials during and after heavy showers commonly exceed 200 mg per liter. When we visited the Red River on 19-20 October 1977 there was evidence that the water level had been about 30 cm higher a short time previously. We could see no significant ecological damage resulting from this occurrence.

Condition of the stream bed - In all three years the substrate at Station 1 above Molycorp property consisted of tightly packed rubble and gravel.

The stream bottom at Station 1A was almost completely covered with silt derived from a pipe break in March 1977, but in October the bottom was clean rubble except for a little silt at the water's edge.

Station 2 had a clean rubble substrate in 1971, 40% covered with tailings in 1976, and about 10% covered with tailings in 1977.

Stations 3 and 5 had relatively clean rubble substrates in all three years. Only at the water's edge and under the rubble was there some silt, and this consisted chiefly of particles having a diameter in excess of 1 mm.

Chemical Conditions

Dissolved oxygen - All determinations close to 100% saturation. This is usual in rapid streams having no organic pollution.

Free carbon dioxide - Always present in equilibrium concentrations of 2 to 3 ppm, corresponding to the partial pressure of CO_2 in air.

Bound CO_2 and hydrogen-ion concentration - All of these data are typical for medium-hard streams, with normal seasonal variations and with slightly increasing hardness at the downstream stations. In general, the waters were softer in 1977 than in 1971 and 1976. This is probably caused by a greater water flow in 1977 but is of no biological significance.

Station	ppm bound CO_2 Oct 1971	Oct 1976	Oct 1977	Hydrogen-ion concentration Oct 1971	Oct 1976	Oct 1977
1	39.0	32.0	27.0	8.1	7.7	7.7
1A	37.0	34.6	29.4		7.7	7.7
2	37.0	31.0	25.3	7.7	7.5	7.4
3	42.0	42.3	36.0	7.6	7.6	7.6
5	38.5	40.0	37.0	8.1	7.7	7.8

Dissolved materials - Quantities of dissolved organic matter (loss on ignition) in the Red River were always low and similar in all three years, - generally less than 0.20 mg per liter, and typical for (organically) unpolluted streams everywhere. Recent streamside disturbances apparently had no measurable effect on organic content. Data for dissolved inorganic matter, however, show considerable variations.

Station	Mg per liter, dissolved inorganic matter Oct 1971	Oct 1976	Oct 1977
1	89.8	98.9	87.0
1A		138.0	
2		114.0	90.9
3		165.2	
5	288.3	371.4	220.2

Dissolved inorganic matter is closely related to local geochemistry, streamside disturbances, and volume of flow. But there is no evidence of abnormal situations in October, 1977. In general, the dissolved inorganic materials were lower in 1977 than in 1976 and 1971. This is possibly a reflection of slightly greater stream flow in 1977, or it may simply be a reflection of normal seasonal variations.

Bottom fauna

Qualitatively, the bottom fauna of October 1977 was similar to the bottom faunas of 1971 and 1976. No "indicator" species have disappeared. They are a typical "clean-water" assemblage, with typical dominant forms in 1977, as follows:

Ephemeroptera (mayfly nymphs)
- Baetis
- Rhithrogena
- Cinygmula
- Ephemerella

Trichoptera (caddis larvae)
- Brachycentrus
- Arctopsyche
- Hydropsyche
- Rhyacophila
- Glossosoma

Plecoptera (stonefly nymphs)
- Pteronarcella
- Isogenus

Diptera (fly larvae)
- Tipula

Coleoptera (beetle larvae)
- elmid larvae

miscellaneous
- small leeches
- planarians

Quantitatively, and for comparative purposes, we may summarize the bottom fauna populations for the three critical sampling dates, expressed as numbers of organisms per square meter in the following table:

	Station	Oct 1971	Oct 1976	Oct 1977
Ephemeroptera	1	12.6	268.8	21.5
	1A		430.1	38.7
	2	88.2	109.8	21.5
	3	67.4	156.2	64.5
	5	67.2	159.1	43.0
Trichoptera	1	16.8	251.6	17.2
	1A		294.4	4.3
	2	48.5	23.8	34.4
	3	63.0	492.5	86.0
	5	369.6	301.0	133.3
Plecoptera	1	0	41.6	8.6
	1A		81.8	25.8
	2	10.5	34.6	0
	3	16.8	21.5	0
	5	8.4	17.2	12.9
Diptera	1	0	0	0
	1A		2.2	0
	2	2.1	0	0
	3	0	60.2	8.6
	5	33.6	81.7	4.3
TOTAL (incl. Misc.)	1	29.4	562.0	55.9
	1A		808.5	43.0
	2	149.3	168.2	81.7
	3	147.2	730.4	159.1
	5	478.8	559.0	223.6

In previous reports we have stressed the wide, natural, normal season-to-season and year-to-year variations in bottom fauna densities, plus the fact that only general trends are significant. Much of the species-by-species population irregularities may be avoided, however, by simply adding together all of the various organisms for each station on each of the three October dates. Thus, the last five lines in the above table are of greatest significance.

Data for the three years at the "control" Station 1 show how great the "normal" population densities may vary from year to year. Indeed, these three sets of figures show as wide a variation as is seldom found in other Rocky Mountain trout streams.* It appears, therefore that October 1977 was a "poor" bottom fauna period, even in an unpolluted and undisturbed area such as Station 1, above the Molycorp property.

Station 1A had the lowest productivity, but there is no great difference between this station and stations 1 and 2. We must conclude that there is no good evidence to show that the low productivity at 1A is the result of streamside excavating and road machine work and plant cutting.

Note, however, that downstream stations in 1977 had progressively higher populations, - a situation generally similar to what was found in 1971 and 1976. Indeed, among the four

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* Pennak, R. W. 1977. Trophic variables in Rocky Mountain trout streams. Archiv für Hydrobiologie. 80: 253-285. (Other important references will be found in our 1971 report.)

taxonomic groups shown in the preceding table, the Ephemeroptera and Trichoptera are most sensitive to environmental disturbance. Yet the "resistant" Plecoptera and Diptera groups are most poorly represented in 1977. We therefore conclude that there is no October evidence of harmful bottom fauna pollution effects on the Red River between the Molycorp plant and stations west of Questa. It would be interesting to assess the bottom fauna again in May or June of 1978 to see the magnitude of the expected resurgence of bottom insects.

A second method of assessing productivity of trout streams is the measure of live weight (biomass) of the bottom animals (as contrasted with numbers), and such data are summarized below:

	Grams of organisms per square meter		
Station	Oct 1971	Oct 1976	Oct 1977
1	0.8	6.0	0.7
1A		6.5	0.3
2	3.6	1.4	2.4
3	2.1	6.6	1.1
5	10.9	5.8	2.5

All stations exhibited generally lower biomass in 1977 than in the two earlier years, but 0.7 grams per square meter at Station 1 (control) indicates an overall poor crop situation in the river rather than any downstream ecological damage. These data parallel those found in many other Rocky Mountain trout streams (Pennak, op. cit.), especially if we are correct in our contention that late 1977 was a generally "poor" fish food period.

Lithophyton

The significance of the lithophyton as an indicator of stream conditions was emphasized in our reconnaissance report of March 1977, and only a brief discussion is necessary here. As shown by a microscopic examination, the patterns of substrate algae in October 1977 were similar to those of October in 1971 and 1976. As shown in the following table, however, the organic contents of the periphyton at stations 1, 1A, and 2 were comparatively low, especially as compared with the "bumper" crop of 1976. Compared with other small trout streams in the Rocky Mountain area, nevertheless, stations 1, 1A, and 2 had quite respectable productivities in October of 1977 (Pennak, *op. cit.*). On the basis of the data we have, we can see no significant scouring effect upon the thin film of algae and detritus covering rubble surfaces. East of Questa and in some stretches west of Questa, the Red River is greatly shaded by overhanging shrubs and trees. Undoubtedly a more open exposure of the stream would markedly increase the production of algae on the rubble surfaces.

	Mg (dry weight) organic matter in the lithophyton per 5-minute sampling period		
Station	Oct 1971	Oct 1976	Oct 1977
1	3.4	112.0	5.4
1A		318.8	3.4
2	12.8	38.3	3.6
3		494.2	97.0
5	39.1	360.9	553.0

Summary and conclusions

On 19 and 20 October 1977, following Red River streamside manipulation with heavy machinery and following removal of some streamside trees and shrubs, we did a very brief stream reconnaissance similar to those performed in October of 1971 and 1976. Field and laboratory conclusions are as follows:

1. Temperature, dissolved oxygen, free carbon dioxide, visual turbidity, pH, and bound carbon dioxide were all typical for this time of year. There were no residual effects of streamside activities or of pipeline breaks during the previous spring.

2. Quantities of suspended materials,determined gravimetrically, were low and similar to those quantities in many other small Rocky Mountain streams during the autumn. The same is true for dissolved materials.

3. The rubble substrate showed no evidence of recent streamside disturbance and gravel wash. All stations below the Molycorp plant showed a great decrease in pipeline silt from the situation in March 1977.

4. The bottom fauna is a "clean water" assemblage of the same forms found previously in the Red River. Quantitatively, however, populations were lower than usual at all stations. We believe that this is simply a reflection of low summer and autumn populations generally in the Red River in 1977.

5. The periphyton standing crop was "typical," although generally lower than it was in October of 1971 and 1976.

6. We can find no biological evidence to show that the stream has suffered recent appreciable damage, especially when we look at the control data for Station 1 and compare them with downstream station data.

Robert W. Pennak

Robert W. Pennak, Professor Emeritus
EPO Biology, Hale 6
University of Colorado
Boulder, Colo. 80309

Copy

Summary Comments on Aquatic Conditions in the Red River, New Mexico, in 1978 as Compared to 1971-1977

ATTACHMENT 7.9

A Report Submitted to the
Molybdenum Corporation of America

by
Robert W. Pennak
EPO Biology
University of Colorado
Boulder, Colo. 80309

1 October 1978

INTRODUCTION

In March and July, 1978, we continued our monitoring of the Red River at five stations above and below the Molycorp mining operations area, and this is a further summary of the situation. To recall our sampling stations:

Station 1 - 100 m above the Molycorp fence line
Station 1A - just above the Goat Hill campground
Station 2 - just above Eagle Rock campground
Station 3 - 100 m above the mouth of Pope Creek
Station 4 - Pope Creek; 50 m above its mouth (not flowing in 1978)
Station 5 - 200 m above the Fish Hatchery

In order to make our data as significant as possible, we are presenting comparative stream readings grouped as follows:

A (Spring) - 17 May 1971, 12-13 March 1977, 29-30 March 1978.
B (Summer) - 23-24 June 1971, 25-26 July 1971, 25-26 July 1978.
C Summary Appendix for certain parameters for all collections in 1971, 1976, 1977, and 1978.

26 JULY POLLUTION INCIDENT

One item in 1978 deserves special attention. Station 1 was the last station to be visited on 26 July. Just as we arrived there at 2:40 p.m. (above Molycorp property), an extremely heavy pollution load was making its way down the River, rendering the water opaque. It consisted of a dense suspension of light tan particles and covered a stretch of water about 2½ miles long. No biological samples could be taken during this pollution. It tapered off slowly. By evening the water was only slightly turbid, and by the next morning the water was again clear. I know nothing about the source of this temporary pollution. Presumably it came from streamside construction work somewhere upriver. There were no showers in the area. At any rate, as is usual in such brief circumstances, no visible damage was done to the stream.

RESULTS AND DISCUSSION

Physical Conditions

Temperatures - Taken routinely, and these data show nothing unusual.

Station	Spring			Summer		
	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	5.5	2.0	9.5	14.0	18.5	
1A		3.8	9.6			13.8
2	6.0	5.0	9.8	16.0	17.5	14.0
3	12.5	2.7	5.2	11.0	12.5	12.0
5	14.7	7.8	9.0	14.6	15.2	13.6

Visual turbidity - Data for 1978 show no important turbidity except for the temporary extremely high turbidity in July.

Station	Spring			Summer		
	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	tr	tr	tr	light	light	extreme**
1A			tr			light
2	tr	light	light	light	light	light
3	tr	light	light	light	high*	light
5	tr	tr	light	tr	high*	light

* - cloudburst in mountains previous evening

** - severe upstream pollution

<u>Gravimetric Turbidity</u> - Gravimetric determinations of suspended organic and inorganic matter are far more accurate than judgement observations or Jackson candle turbidity measurements, and these data follow. Note that all readings in 1978 showed only traces of suspended organic matter. Suspended inorganic matter was never higher than "normal," except for Station 1 in July.

Suspended Organic matter, mg per liter:

	Spring			Summer		
Station	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	0.8	<0.2	<0.2	2.7	3.5	<0.2
1A		<0.2	<0.2			<0.2
2		<0.2	<0.2			<0.2
3	16.6	<0.2	<0.2	1.2	18.8	<0.2
5	6.9	<0.2	<0.2	1.8	18.9	<0.2

Suspended Inorganic matter, mg per liter:

	Spring			Summer		
Station	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	3.6	9.3	9.3	15.0	26.0	324.3**
1A		48.3	7.1			24.6
2		71.2	10.7			31.6
3	17.6	18.4	8.6	3.4	193.8*	13.7
5	6.9	8.9	8.0	5.3	181.8*	28.5

* - cloudburst in mountains previous evening

** - severe upstream pollution

Stream Bed Mill Waste - By 1978, essentially all mill waste spill residue generated in earlier years had disappeared. The substrate at all stations was essentially normal with a predominance of rubble, small boulders, and a little gravel. A small amount of clay, probably generated in the 1978 spring runoff, still remained near shore, but was of no biological significance. The thin yellowish-tan chemical deposit on the rubble at Station 2 was much less abundant in July than in March, 1978. This material is thought to be derived from naturally-occurring surface streamside deposits upstream from Station 2.

Chemical Conditions

Dissolved oxygen - All determinations close to 100% saturation. This is usual in shite-water streams having no organic pollution.

Free carbon dioxide - Always present in equilibrium concentrations of 2 to 3 ppm, corresponding to the partial pressure of carbon dioxide in air.

Bound carbon dioxide - All of these data, expressed as ppm, are typical for medium-hard streams, with normal seasonal variations. Note that the water becomes harder in passing from Station 1 to Station 5, as it picks up more and more solute from the substrate. This is typical of small flowage systems everywhere in the world.

Station	Spring			Summer		
	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	29.0	29.7	25.0	33.5	35.1	
1A		35.0	22.5			24.2
2		21.0	20.5			25.0
3	50.0	47.5	30.1	49.0	45.0	32.5
5	45.0	40.4	31.0	45.0	40.5	32.8

Total Dissolved Solids - The Federal and state governments now ordinarily express dissolved materials in the form of total dissolved solids (TDS), without splitting into organic and inorganic fractions, unless there is domestic or industrial pollution contributing organic materials to the water. In unpolluted mountain streams the dissolved organic fraction is of little significance, by itself. TDS data are expressed as mg per liter.

Station	Spring			Summer		
	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	14.6	141.0	177.5	139.1	123.0	169.9
1A		129.2	99.4			120.0
2		172.4	150.6			99.8
3		248.2	241.5			155.4
5	31.9	570.9	204.8	554.3	657.7	188.6

This table shows the natural wide TDS variations that may be found in mountain streams from time to time, depending on the vagaries of rains, snowmelt, and runoff. In some instances, in early years, there is evidence to show that Pope Creek water increased the TDS of the Red River, especially in 1971, 1976, and 1977, but we have already shown that this phenomenon has a beneficial fertilizing effect on the Red River biotic community. At any rate, there is no evidence to show that Molycorp operations have any deleterious effects on the TDS picture for the Red River.

Bottom Fauna

From the standpoint of the particular species make-up, the bottom fauna in 1978 was essentially the same or slightly richer than in those collections made in earlier years. The same four major clean-water groups dominated the communities: mayfly nymphs, caddis larvae, stonefly nymphs, and fly larvae. Data are expressed as numbers of organisms per square meter.

	Spring			Summer		
Station	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	98.7	112.0	958.9	210.0	109.2	
1A		210.8	1677.2			442.9
2	31.5	554.7	51.7	73.6	58.8	490.2
3	290.0	2017.7	907.3	215.0	326.3	210.7
5	298.2	1874.7	1401.8	478.8	198.6	2206.8

Note that the 1978 populations at these five stations were exceptionally high, for the most part higher than in 1971 and 1977. The only important exception was the sparse population at Station 2 in March of 1978, but it had recovered by July of 1978.

As a supplement to numerical abundance of bottom animals, it is essential that we also present live weight (biomass) data for the same samples. Such data are given below, as grams of organisms per square meter.

	Spring			Summer		
Station	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	1.7	1.7	7.3	4.2	4.0	
1A		4.5	32.3			5.2
2	2.9	7.8	0.5	1.1	2.9	16.3
3	7.1	17.3	6.2	3.8	5.0	1.8
5	10.9	51.6	18.5	16.8	13.7	21.1

Here again the population was exceptionally low at Station 2 in March, 1978, where the substrate had the thin brownish adherent coat of sediment. By July, 1978, however, the population had recovered. All other samples were within or well above the normal range of biomass figures published for other Rocky Mountain trout streams (Pennak 1977).

Lithophyton

The composition and development of the thin layer of algae and dead organic matter on the exposed surfaces of stones is an indicator of the general condition of the biotic community. As soon as the water contains enough sediment to have a scouring action or as soon as toxic materials make their way into the water, then the periphyton quickly loses much of its variety of algae (diatoms, greens, and blue-greens), and the community quickly disintegrates. Our data are expressed as mg dry organic matter per 5-minute sampling period.

	Spring			Summer		
Station	May 1971	Mar 1977	Mar 1978	Jun 1971	Jul 1971	Jul 1978
1	1.9	220.9	112.5	1.0	0.4	
1A		1669.3	3012.0			0.9
2	69.1	8.4	34.5	2.1	8.3	110.8
3	12.9	333.1	560.9	1.0	0.6	246.3
5	4.6	7119.0	1792.5	0.7	95.0	937.5

In past years Station 2 always had a sparse lithophyton, but in March and July of 1978 the community was well developed. The table emphasizes the enormous quantitative differences of lithophyton from time to time and place to place. Such quantitative differences are seasonal and usually related to the effect of the sedimentary load during the spring runoff: high population through March, decreasing markedly in April, May, June, and sometimes early July, increasing again by late July. Qualitatively, the lithophyton in March and July of 1978 was a well developed "clean water" situation.

CONCLUSIONS

Sampling of the five permanent stations along the Red River in March and July of 1978 showed that the physical and chemical nature of the stream as well as the biotic community were essentially "normal." Station 2 had some unusual conditions in March but was much improved by July. In comparing the 1978 data with those of previous years, it appears that the Red River is now an improved, stable stream.

Reference: Pennak, R. W. 1977. Trophic Variables in Rocky Mountain Trout Streams. Arch. Hydrobiol. 80: 253-285.

APPENDIX

By now, we have taken sufficient data over the years at the Red River to give us some significant idea of <u>average</u> conditions at the various stations, in spite of considerable year-to-year and season-to-season variations. All such data are therefore summarized below with the idea that they may serve as a good comparison pattern for open season conditions. If and when additional data are taken in future years, we recommend that such data be compared with the following tabular material, bearing in mind that plus or minus variations in all of these categories are the normal situation.

Average aquatic conditions in the Red River, based on data taken in 1971, 1976, 1977, and 1978. Data for one cloudburst and two pollution incidents are omitted.

	Station 1	1A	2	3	4	5	Probable normal variation for any one determination
Temperature	10.9	9.2	10.6	8.2	11.4	11.5	± 5°
Suspended load, mg per liter	23.0	19.4	27.7	12.8	24.5	16.0	± 80%
Bound carbon dioxide, mg per liter	31.4	30.4	28.1	42.9	27.2	40.2	± 25%
Total dissolved solids, mg per liter	133.9	133.6	144.6	217.0		366.0	± 60%
Bottom fauna, organisms per square meter	239	628	160	522	529	768	± 50%
Bottom fauna, grams per square meter	3.2	9.7	3.9	5.0	2.3	14.1	± 50%

Summary Comments on Aquatic Conditions in the Red River on 29-30 March 1978

Our early spring results this year are most significant when compared with data taken in May of 1971 and March of 1977.

Temperature, turbidity - roughly comparable in all three years.

Suspended organic and inorganics - all comparable and negligible, in spite of much higher runoff in 1978.

Stream bed mill waste - in 1978 there was no significant particulate mill waste on the substrate at any of the five Red River stations. Rubble was the only important component. This is in accordance with our prediction of a year ago. At Station 2, however, just above Eagle Rock Campground, much of the rubble surface was partially covered with a thin yellowish-tan chemical deposit that has occurred here previously (though never so abundantly). When we found it in 1977 we assumed that it was derived from the previous spill, but such is presumably not the case. This deposit can be scraped off the rubble with a scalpel. It should eventually disappear by scouring action unless more of it is contributed to the river. We assume it has originated from Molycorp operations, either directly (from drainage?), or from a side gulch. It is not a "naturally occurring" substance, and we do not know its chemical nature. Undoubtedly the Molycorp chemists are aware of its presence.

Dissolved oxygen, free carbon dioxide, bound carbon dioxide, pH - comparable to spring conditions in 1971 and 1977.

Dissolved inorganic matter - lower this year than in 1977. Higher than in 1971.

Dissolved organic matter - low, as usual, and of no importance at this time.

Bottom animals, numbers per square meter -

Station	1971	1977	1978
1, above Molycorp preperty	94.5	112.0	958.9
1A, above Goat Hill Campground	-	210.8	1677.2
2, above Eagle Rock Campground	31.5	554.7	51.7
3, above mouth of Pope Creek	283.1	2017.7	907.3
4, Pope Creek	10.5	8.6	-
5, 200 m above Fish Hatchery	298.2	1874.7	1401.8

Bottom animals, grams per square meter -

1	1.7	1.7	7.3
1A	-	4.5	32.3
2	2.9	7.8	0.5
3	7.1	17.3	6.2
4	0.1	0.1	-
5	10.9	51.6	18.5

The 1978 spring standing crop of bottom organisms was healthy and generally comparable or higher than those in 1971 and 1977, <u>except at Station 2</u>. We urge that no further chemical(?) effluent be added to the stream to perpetuate the thin coat of material on the rocks at this station. Undoubtedly the reduced fauna here is the result of this abnormal situation. Even some of the bottom animals had a coating of this substance.

Lithophyton (coating of organic food material on stream rubble), mg organic matter per five-minute sample -

Station	1971	1977	1978
1	1.9	220.9	112.5
1A	-	1669.3	3012.0
2	69.1	8.4	34.5
3	12.9	333.1	560.9
4	5.0	2791.4	-
5	4.6	7119.0	1792.5

The lithophyton food material was again abundant in 1978, except at Station 2, where the productivity is undoubtedly inhibited by the coating on the rocks.

16 May 1978

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Copy

ECOSYSTEM CONDITIONS IN THE RED RIVER IN THE LATE SUMMER OF 1979: EFFECTS OF ABNORMALLY HIGH RUNOFF

ATTACHMENT 7.10

Report submitted to the

Molybdenum Corporation of America

by

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December, 1979

INTRODUCTION

On 5-6 August and 9-10 September of 1979 we continued our biological monitoring of the Red River. In addition to our usual six stations, however, we added two additional downstream sites. The entire list of eight stations was therefore:

Station 1 - 100 m above the Molycorp fence line
Station 1A - just above the Goat Hill campground
Station 2 - just above the Eagle Rock campground
Station 3 - 100 m above the mouth of Pope Creek
Station 4 - Pope Creek; 50 m above its mouth (not flowing)
Station 5 - 200 m above the Fish Hatchery
Station 6 - 0.8 km below the west edge of the Fish Hatchery
Station 7 - 0.4 km above the mouth of the Red River

Stations 6 and 7 were new and were established as a consequence of impending court hearings involving Molycorp and the Federal Government. Station 6 was somewhat similar to all of the other upstream stations, but the actual rubble sampling area was restricted owing to the presence of many boulders. At Station 7 the river is essentially a narrow torrent traversing a bed of small to large boulders. No suitable rubble substrate could be found, and consequently no bottom fauna samples could be taken.

This report is intentionally brief. Methodology follows those procedures used in previous reports in this series, to which reference should be made for details. Literature references are also to be found in earlier reports.

1979 RUNOFF

The spring and summer were notable for their abnormally high runoff, - said to be the most violent in 40 years. The streamside was heavily flooded and damaged by the torrential waters. Trees and shrubs were abundantly uprooted. The original rubble stream bed was heavily scoured and cleaned of interstitial organic debris and sand. In fact, the Red River did not reach a semblance of its "normal" flow until after the middle of July. In spite of marked alterations in the stream bed and streamside, the high runoff afforded an ideal opportunity for us to assess the damage to the bottom (fish food) organisms.

RESULTS AND DISCUSSION

Physical Conditions

Temperatures - taken routinely; these data show conditions similar to those in previous years.

Station	5-6 August	9-10 September
1	15.0	14.2
1A	15.0	13.3
2	15.7	13.3
3	11.0	10.2
4	(no water)	(no water)
5	12.9	12.0
6	14.9	16.0
7	12.0	13.0

Visual Turbidity - Water was clear to only slightly turbid at all stations on both dates.

Gravimetric Turbidity - Following our custom in previous work on the Red River, we made gravimetric determinations of suspended materials for our samples. The organic fraction of all samples was very low, - less than 0.2 mg per liter. The suspended inorganic materials, however, showed the following pattern (expressed as mg per liter):

Station	5-6 August	9-10 September
1	5.1	18.0
2	8.1	12.6
5	4.8	7.7
6	8.2	29.5
7	10.5	14.3

Note first that all readings were generally higher in September than in August. We have no explanation for this situation other than to assume that there must have been some headwater disturbance or precipitation in the latter period. Ordinarily water is clearer in September than in August. Note also that the highest reading was 29.5 mg in September, below the Fish Hatchery. Possibly hatchery operations were responsible for this (temporary ?) situation. In general, however, all readings were well within the range of "normal" conditions found in previous years, and, indeed, they closely follow the situation in other small mountain streams everywhere in the Rocky Mountains.

Stream Bed Conditions

Although we have no quantitative measurements, it was abundantly evident that the stream bed in 1979 was different from what it was in 1971 to 1978. Most notably, the extremely high and persistent spring and summer runoff had a "scouring" effect on the basically rubble substrate and washed away most of the macroparticulate organic debris as well as interstitial sand and clay particles. In effect, this is a "cleansing" action which is sooner or later experienced by all streams. Some stream biologists (unpublished) are convinced that such periodic "scours" are actually beneficial in the long run because they serve to improve the structure of the rubble substrate by increasing the total interstitial area available for periphyton and the total interstitial volume for macroscopic fish food organisms.

Chemical Conditions

Dissolved Oxygen - Determinations at Stations 1, 3, 5, and 6 were all close to 100% saturation, as is customary in unpolluted white-water streams.

Free Carbon Dioxide - Similarly present in concentrations of 2 to 3 ppm, corresponding to the partial pressure of carbon dioxide in air.

Bound Carbon Dioxide - All readings were in the medium-hard range and similar to readings taken in previous years. This situation indicates a somewhat higher productivity potential than in most (softer) small mountain streams. Note the usual downstream hardness increase. Results are expressed as ppm of bound carbon dioxide.

Station	5-7 August	9-10 September
1	20.0	25.0
1A	25.2	17.5
2	25.5	25.0
3	27.5	38.0
4	(no water)	(no water)
5	30.0	33.0
6	30.5	35.0
7	31.0	37.0

Total Dissolved Solids - Most laboratories now ordinarily express dissolved materials in the form of total dissolved solids (TDS), without splitting into organic and inorganic fractions, unless there is domestic or industrial pollution contributing organic materials to the water. By itself, the dissolved organic fraction is of little significance in mountain streams. Results are expressed as mg per liter.

Station	5-7 August	9-11 September
1	99.0	141.6
7	170.6	241.4

In general, these results are lower than those found in previous years. This may be due to the fact that the ("low") flow in August and September of 1979 was actually higher than it was during most other sampling periods in previous years.

Bottom Fauna

During the two Red River field trips in 1979 fish food organisms were taken as usual on rubble substrates at stations 1 to 5. The new downstream stations 6 and 7, however, were visited for the first time and presented a problem. At Station 6, 0.8 km downstream from the hatchery, the percentage of rubble substrate was markedly reduced, and the stream bed consisted chiefly of small to large boulders. Nevertheless, we did locate an area suitable for quantitative and quantitative samples. Rubble is well known as the most productive kind of substrate, and since it accounted for less than 10% of the total bottom area near Station 6, we may assume that the stream as a whole is a poor producer in this particular area.

In the area of Station 7 we were unable to locate any suitable rubble substrate. The stream bed here consists almost entirely of low-producing boulders and bedrock. In addition, the water was almost everywhere quite deep over the very narrow stream bed so that the Surber sampler could not be used even if there were suitable rubble bottom. Consequently we have no bottom fauna data from Station 7. We did, however, see a few caddis larvae cases on some of the rocks.

In general, the same genera and same orders of bottom insects made up the bottom fauna in 1979 as in previous years. Furthermore, we could see no significant differences between the relative proportions of Ephemeroptera (mayfly nymphs), Trichoptera (caddis larvae), Plecoptera (stonefly nymphs), and Diptera (fly larvae) in 1979 as compared with previous years.

As in previous years, the Red River had a low species diversity. Forms taken in 1979 were as follows:

Ephemeroptera
- Baetis
- Cinygmula
- Epeorus
- Ephemerella
- spp.

Trichoptera
- Brachycentrus
- Hydropsyche
- Arctopsyche
- sp.

Plecoptera
- Sweltsa
- Pteronarcella
- Isoperla
- spp.

Diptera
- Atherix
- Chironomidae
- Tipulidae
- Simuliidae

Miscellaneous
- Physa
- Dytiscidae

Since we have bottom fauna data from as far back as 1971, perhaps the most accurate way to judge the 1979 situation is to compare the average productivity of 1971-1979 with the 1979 population. Such data are as follows, expressed as grams of organisms per square meter of substrate.

Station	1971-1979	August 1979	September 1979
1	2.8	1.6	0.4
1A	6.6	0.6	0.6
2	3.4	0.2	1.0
3	4.6	2.4	2.0
4	2.4		
5	12.3	3.4	1.0
6	1.4	1.7	1.4
(Average)	4.8	1.7	1.1

The 1979 productivity was quite low, although not as low as the productivity in certain other small Front Range mountain streams. Undoubtedly the situation in 1979 was the direct result of the abnormally high runoff during the spring and early summer. Such spates, especially if continued for some months, have the effects of (1) dislodging and washing bottom organisms downstream, (2) macerating the organisms by the molar action of sand and gravel, and (3) by inhibiting reproduction. In spite of the most turbulent conditions, however, there are always a few eggs and immatures below the substrate surface that function as a "seed" population when conditions return to normal. Thus, there is no question about the regeneration of normal faunal densities in the Red River by the summer of 1980. The present writer has seen other streams successfully "recover" from similar spates.

Lithophyton

The high water of spring and summer of 1979 had a severe scouring effect on the thin layer of living and dead organic matter normally covering all exposed surfaces on stream beds. This material, consisting of microdetritus, algae, and bacteria, serves as a food source for the bottom insects. Results for 1979 are as follows, expressed as mg of organic matter collected per 5-minute sampling period.

Station	August 1979	September 1979
1	1.1	26.8
1A	4.0	34.3
2	6.9	
3	1.1	234.2
5	8.6	133.4
6	9.0	124.8

Note the marked increase between August and September. This augurs well for food conditions for aquatic insects, and is further evidence of the rapidity of biotic recovery in the Red River. Although the vast majority of particulate material in all lithophyton samples was non-living, there was nevertheless a noticeably greater percentage of living algal cells in September than in August.

SUMMARY

In 1979 two further field trips were made to monitor biotic conditions in the Red River, one in August and one in September. In addition to the usual six river stations, two new ones were added. One (number 6) was located 0.8 km below the west edge of the Fish Hatchery and the other (number 7) 0.4 km above the mouth of the Red River. Sampling of bottom fauna was difficult at station 6 and impossible at station 7 because of the boulder-bedrock substrate, deep water, and swift current.

Temperature conditions were all "normal," and turbidity was low and negligible.

The stream bed showed great evidence of scouring and cleaning by the torrential spring and summer runoff. This is believed to be a biotic improvement.

Dissolved oxygen, free carbon dioxide, bound carbon dioxide, and total dissolved solids were all "normal."

The standing crop of bottom insects was greatly reduced but it was no worse than the population in many other small mountain streams. There is no doubt that this situation was produced by the long spate of 1979. There was no evidence of extermination of any species. Restoration of normal population conditions should be achieved by the summer of 1980.

The lithophyton was also much reduced for the same reason, but September already showed considerable recovery over August conditions.

Molycorp operations had no effect upon the economy of the Red River in 1979.

CONCLUDING OBSERVATION

Sampling in 1979 showed conclusively that a natural stream catastrophe of much greater magnitude than any man-made catastrophe can be tolerated by the stream organisms, and that populations are quick to regenerate and move toward normal levels.

Special Reference to Litigation at Santa Fe, autumn 1979

Bottom fauna samples and routine chemical analyses were determined for the Red River and Pope Creek in various months in 1971, 1976, 1977, 1978, and 1979. Sampling stations were as follows:

1. 100 meters above Molycorp property.
1A. 100 meters above Goat Hill campground.
2. 100 meters above Eagle Rock campground.
3. 50 meters above mouth of Pope Creek.
4. Pope Creek, 50 meters above its mouth.
5. 200 meters above the east edge of the Fish Hatchery.
6. 0.8 km below the west edge of the Fish Hatchery.
7. 0.4 km above the mouth of the Red River. (The substrate here is essentially all large boulders, making it impossible to take bottom fauna samples.)

Bottom Fauna

The chief characteristic of the botton fauna of any river is its quantitative variability at any one station, depending on the season of the year, hydrological conditions, and the seasonal cycles of abundance of the many species of animals making up the bottom fauna. These factors are in addition to the nature of the substrate and the inherent error in taking randon samples. Most investigators take only one or two samples at a time at a particular station. Our data, however, are based on five replicates taken at one time at a particular station. We therefore feel that they will stand up statistically to a greater degree than most stream bottom fauna data.

The major groups of organisms and the specific genera found in the Red River are those typical of small western trout streams everywhere, name Plecoptera (stonefly) nymphs, Ephemeroptera (mayfly) nymphs, Trichoptera (caddis) larvae, and Diptera (fly) larvae. In all of our Red River studies, there is no evidence of the selective elimination of any particular group or species of bottom animal as the result of ecological variables in the stream. Because of its intermittent nature, however, Pope Creek (Station 4) does not have the time to develop a permanent, typical, and abundant fauna.

Any stream subject to continuous severe turbid conditions, or the presence of continuous organic pollution or excessive quantities of toxic substances quickly loses its characteristic fauna. There is no evidence of such drastic alterations in our data. Furthermore, we have no evidence of any permanent change in the fauna as the result of severe hydrological conditions.

All of our Red River fish food data are summarized in Table I where the results are expressed as grams of fish food organisms per square meter of substrate. In spite of the wide range of standing crops, all of these figures are well within the range to be expected in small western trout streams everywhere. This generalization is borne out by the data given in Pennak (1977) which are based on many replicate collections at 51 stations on trout streams in Montana, Wyoming, Idaho, Colorado, and New Mexico.

Pennak, R. W. 1977. Trophic variables in Rocky Mountain trout streams. Arch. Hydrobiol. 80: 253-285.

Table I. Average bottom fauna, grams per square meter.

	Station 1	1A	2	3	4	5	6	7	Average
1971 May-Nov	2.7		2.3	3.7	3.0	7.8			3.9
1976 Oct	6.0	6.5	1.4	6.6	3.3	5.8			4.9
1977 Mar	1.7	4.5	7.8	17.3	0.1	51.6			13.8
1977 Oct	0.7	0.3	2.4	1.1		2.5			1.4
1978 Mar & Jul	7.3	18.9	8.4	4.0		19.8			11.7
1979 Aug	1.6	0.6	0.2	2.4		3.4	1.7		1.7
1979 Sep	0.4	0.6	1.0	2.0		1.0	1.0		1.0
Average	2.9	5.2	3.4	5.3	2.1	13.1	1.4		5.5

In addition, several tentative conclusions may be drawn from the data in Table I:

1. Note that the bottom fauna at Station I (above Molycorp) is roughly similar to those at the other stations. There is no evidence of downstream degradation.

2. Note that Station 5 (below Pope Creek inlet) appears to have the highest productivity. It is not impossible that water from Pope Creek has a growth-promoting effect on the Red River.

3. As noted above, Pope Creek itself (Station 4) has a consistently poor fauna because of its intermittent flow, even though smaller populations were sometimes found at other stations.

4. There is some evidence that the massive runoff in the spring and summer of 1979 has temporarily depleted the bottom fauna in the Red River. Conditions should soon return to normal, however.

The most significant figures in Table I are those in the bottom line. The writer knows of no journal literature reference material based on so many quantitative bottom fauna samples for a few kilometers of a single trout stream.

Stream Flow

Severe floods and droughts are natural phenomena in all running waters, and the ability of fish food organisms to withstand and adjust to these conditions was operational long before man first appeared on the earth. Indeed, stream fishes are equally well adapted to temporary unfavorable conditions.

In general, there is a direct correlation between average size of stream and the size of a resident trout population. Our finest trout waters are invariably our largest streams. Natural fish populations can maintain themselves, however, even through the most severe drying conditions. For example, the Rio Grande just north of the New Mexico line had a mean discharge of only 9.7 cfs between 1 and 7 October 1964. In the same area the writer in October of 1978 walked across the Rio Grande without wetting his garters. In Colorado, four streams about the size of the Red River (Piceance, Boulder, South Boulder, and Lefthand) commonly deliver less than 5 cfs during dry months. All have resident trout populations. The South Platte below Cheesman dam in Colorado, famous for its trophy trout, had a flow of only 15 cfs or less during the entire winter of 1978-1979.

Suspended Load

Similarly, the botton fauna and trout populations are able to maintain themselves for surprisingly long periods of heavy silting, especially during spring and summer runoff. Long stretches of the Rio Grande and the Colorado River, for example, are classical textbook pictures. Most trout streams below 9000 feet have heavy suspended loads for long periods every year, often up to 300 ppm. These are in addition to temporary severe silting produced by thunderstorms and heavy rains.

The suspended loads for all of our Red River data are shown in Table II. Note that except for temporary tailings problems and cloudbursts, all readings were 91 ppm or below, and the average for Pope Creek was only 28 ppm. The FAO report to the United Nations in 1965 states: "Usually ppssible to maintain good or moderate fisheries in waters which normally contain 25-80 ppm suspended solids." Thus the Red River has a favorable suspended load situation.

Table II. Suspended solids in the Red River, ppm, by station.

1	1A	2	3	4	5	6	7
4	7	155**	20	19	8	8	11
18	48	27	5	21	7	30	14
30	10	12	213*	46*	201*		
36	7	5	16	13	22		
35	25	2	90	91	26		
38		5	17	19	41		
8		71	18	5	9		
10		14	12	6	8		
9		11	9		29		
324***		8			8		
5		8					
18		13					

* - Upstrean cloudburst the previous evening.
** - Burst tailings pipe one mile below plant the previous evening.
*** -Severe pollution upstream from Molycorp; source unknown; lasted about four hours.

Total Dissolved Solids

High total dissolved solids, and especially carbonates and bicarbonates, have an important role in maintaining high insect and fish productivity in streams, although the precise mechanisms are unknown. Furthermore, it is now well known that the dissolved solids are important in combining with heavy metals and protecting the bottom fauna and fish faunas. In these respects, the Red River is especially fortunate in having "medium" to "hard" carbonate waters and unusually high TDS readings, as shown in Table III.

Table III. Total dissolved solids, mg per liter, by station.

1	1A	2	3	4	5	6	7
15	186	156	223	1308	32		170
139	119	156	233	318	549		241
123	99	91	242		657		
157	120	151	155		488		
125		100			360		
154					219		
136					464		
139					546		
87					220		
178					241		
170					189		
99							
142							

A further relection of these advantages is the fact that hydrogen-ion readings ranged from pH 7.0 to pH 8.1, with most readings being 7.6 to 7.8. This is an exceptionally favorable alkaline situation; most mountain waters are close to neutrality.

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RESULTS AND DISCUSSION

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- _Epeorus_
- _Ephemerella_
- spp.

Trichoptera
- _Brachycentrus_
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- _Arctopsyche_
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- _Sweltsa_
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Diptera
- _Atherix_
- Chironomidae
- Tipulidae
- Simuliidae

Miscellaneous
- _Physa_
- _Dytiscidae_

Since we have bottom fauna data from as far back as 1971, perhaps the most accurate way to judge the 1979 situation is to compare the average productivity of 1971-1979 with the 1979 population. Such data are as follows, expressed as grams of organisms per square meter of substrate.

Station	1971-1979	August 1979	September 1979
1	2.8	1.6	0.4
1A	6.6	0.6	0.6
2	3.4	0.2	1.0
3	4.6	2.4	2.0
4	2.4		
5	12.3	3.4	1.0
6	1.4	1.7	1.4
(Average)	4.8	1.7	1.1

The 1979 productivity was quite low, although not as low as the productivity in certain other small Front Range mountain streams. Undoubtedly the situation in 1979 was the direct result of the abnormally high runoff during the spring and early summer. Such spates, especially if continued for some months, have the effects of (1) dislodging and washing bottom organisms downstream, (2) macerating the organisms by the molar action of sand and gravel, and (3) by inhibiting reproduction. In spite of the most turbulent conditions, however, there are always a few eggs and immatures below the substrate surface that function as a "seed" population when conditions return to normal. Thus, there is no question about the regeneration of normal faunal densities in the Red River by the summer of 1980. The present writer has seen other streams successfully "recover" from similar spates.

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The high water of spring and summer of 1979 had a severe scouring effect on the thin layer of living and dead organic matter normally covering all exposed surfaces on stream beds. This material, consisting of microdetritus, algae, and bacteria, serves as a food source for the bottom insects. Results for 1979 are as follows, expressed as mg of organic matter collected per 5-minute sampling period.

Station	August 1979	September 1979
1	1.1	26.8
1A	4.0	34.3
2	6.9	
3	1.1	234.2
5	8.6	133.4
6	9.0	124.8

Note the marked increase between August and September. This augurs well for food conditions for aquatic insects, and is further evidence of the rapidity of biotic recovery in the Red River. Although the vast majority of particulate material in all lithophyton samples was non-living, there was nevertheless a noticeably greater percentage of living algal cells in September than in August.

SUMMARY

In 1979 two further field trips were made to monitor biotic conditions in the Red River, one in August and one in September. In addition to the usual six river stations, two new ones were added. One (number 6) was located 0.8 km below the west edge of the Fish Hatchery and the other (number 7) 0.4 km above the mouth of the Red River. Sampling of bottom fauna was difficult at station 6 and impossible at station 7 because of the boulder-bedrock substrate, deep water, and swift current.

Temperature conditions were all "normal," and turbidity was low and negligible.

The stream bed showed great evidence of scouring and cleaning by the torrential spring and summer runoff. This is believed to be a biotic improvement.

Dissolved oxygen, free carbon dioxide, bound carbon dioxide, and total dissolved solids were all "normal."

The standing crop of bottom insects was greatly reduced but it was no worse than the population in many other small mountain streams. There is no doubt that this situation was produced by the long spate of 1979. There was no evidence of extermination of any species. Restoration of normal population conditions should be achieved by the summer of 1980.

The lithophyton was also much reduced for the same reason, but September already showed considerable recovery over August conditions.

Molycorp operations had no effect upon the economy of the Red River in 1979.

CONCLUDING OBSERVATION

Sampling in 1979 showed conclusively that a natural stream catastrophe of much greater magnitude than any man-made catastrophe can be tolerated by the stream organisms, and that populations are quick to regenerate and move toward normal levels.

cc Sacrison
Ferland

Copy

AQUATIC ECOSYSTEM CONDITIONS IN THE RED RIVER, NEW MEXICO, IN JULY, 1981

ATTACHMENT
7.11

Report submitted to the
Molybdenum Corporation of America

by

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October 1981

M-00000766

INTRODUCTION

On 18-19 July 1981 we continued our biological monitoring of the Red River. Our list of sampling stations is as follows:

Station 1 - 100 meters above the Molycorp fence line.

Station 1A - just above the Goat Hill campground.

Station 2 - just above the Eagle Rock campground.

Station 3 - 100 meters above the mouth of Pope Creek.

Station 4 - Pope Creek; 50 meters above its mouth.

Station 5 - 200 meters above the Fish Hatchery.

Station 6 - 0.8 km below the west edge of the Fish Hatchery.

Station 7 - 0.4 km above the mouth of the Red River. (Because of illness combined with the excessive heat on the morning of 20 July, we could not make the descent to this (last) canyon station. This is a torrential boulder station which is not so important as the other seven upstream stations.)

This report is intentionally brief and is designed for comparison with data reported in previous years. Methodology follows those procedures used in all other Red River reports, to which reference should be made for details. Pertinent literature references are also to be found in earlier reports.

1981 RUNOFF

In 1979 and 1980 the Red River runoff was abnormally high, in striking contrast to 1981 when the runoff was much below normal. The biotic data gathered in 1981 are therefore especially useful for detecting low-water faunal changes which might be ascribed to natural conditions as opposed to any silting resulting from Molycorp's operations.

RESULTS AND DISCUSSION

Physical Conditions

Temperatures - taken routinely; these data show changes from July conditions in previous years, presumably because of low water and high air temperatures in 1981. Stations 1 through 3, especially, were several degrees above "normal." However, none of the readings were high enough to indicate any damage to the aquatic community.

Station 1	17.8°
1A	18.0
2	19.0
3	12.8
4	20.0
5	15.8
6	18.0

Visual turbidity - Stations 1A and 2 showed slight, but normal, silting. Stations 1, 3, 5, and 6 had negligible silting. Station 4, however, carrying runoff from the Molycorp settling pond was clearest of all. Stream biologists characterize such water as "gin-clear."

Gravimetric turbidity - The organic fraction of the suspended load was less than 0.2 mg per liter at all seven stations, and the inorganic fraction was everywhere less than 5 mg per liter. Collectively, these are the lowest readings we have ever made on the Red River.

Stream Bed Conditions

The appearance of the stream substrate in 1981 was generally similar to conditions in 1979 at stations 1, 3, 5, and 6. The bed of Pope Creek (Station 4) was entirely free of fine tailings, in contrast to the situation in 1978.

Stations 1A and 2 in the present year, however, still had hard-packed tailings obscuring some of the substrate between boulders and pieces of rubble, especially near the water's edge. Nevertheless, the situation was somewhat cleaner than we found it during our previous visit in 1979. These two stations (at Goat Hill and Eagle Rock) are the only continuing problems. Both the stream bed and the streamside soils are slow to be cleared of their residual tailings by the normal surface drainage and stream scouring action.

Chemical Conditions

Dissolved oxygen and free carbon dioxide determinations were considered superfluous and were not made in 1981. All Red River oxygen readings in previous years were close to 100% saturation, as is customary in white-water mountain streams; and all free carbon dioxide readings in previous years were 2 to 3 parts per million, also in keeping with conditions in such streams.

Bound carbon dioxide - All readings were in the medium-hard range (10 to 40) and similar to data taken in previous years. In general, these levels of bound carbon dioxide are higher than we expect in Rocky Mountain montane flowages; they indicate a favorable level of biological productivity.

Station	ppm bound CO_2
1	28.8
1A	23.5
2	22.0
3	37.0
4	26.5
5	36.0
6	40.5

Hydrogen-ion concentration - pH readings were similar to those of previous years, and ranged from pH 7.4 at Station 2 to pH 8.1 at Station 6. Most montane stream waters in our area usually range from pH 6.8 to 7.3, so the Red River is markedly more alkaline and, potentially, more productive.

Total dissolved solids - Representative determinations of TDS showed some unusual results:

Station	mg per liter
Station 1	98.5 mg per liter
2	189.7
4	2432.9
5	588.5

All figures are higher than midsummer data we have for past years. Stations 1, 2, and 5 show the normal downstream increase in dissolved solids as it is manifested in any flowage. The specific amounts, however, are probably a reflection of low flow in the Red River in 1981, - a widespread phenomenon familiar to hydrologists. The water at Station 4 (Pope Creek) is runoff from the Molycorp settling pond, and this is by far the highest TDS figure we have ever found in our Red River studies. There is, however, no evidence that such water has a damaging effect on the Red River water below the mouth of Pope Creek. In fact, quite the opposite may be true.

BIOLOGICAL CONDITIONS

Bottom Fauna

In general, the same genera of bottom insects made up the bottom fauna in July 1981 as in previous years. Furthermore we could see no significant differences between the relative proportions of Ephemeroptera (mayfly nymphs), Trichoptera (caddis larvae), Plecoptera (stonefly nymphs), and Diptera (fly larvae) in 1981 as compared with previous years.

The various taxa taken in 1981 are as follows:

Ephemeroptera
- *Baetis*
- *Cinygmula*
- *Ephemerella*

miscellaneous
- Elmidae
- Annelida
- planarians
- *Physa*

Trichoptera
- *Brachycentrus*
- *Arctopsyche*
- *Hydropsyche*
- *Orthotrichia*
- sp. A
- sp. B
- sp. C

Plecoptera
- *Pteronarcella*
- *Isoperla*
- sp. A
- sp. B

Diptera
- *Atherix*
- Chironomidae
- Simuliidae
- Tipulidae

This list of 22 forms exceeds all other collections that we have made from the Red River, the usual list amounting to only 12 to 17 taxa. It is difficult to tell whether or not this represents permanent improvement in the structure of the biotic community, chiefly because of the variable structure of the bottom fauna. But at any rate the outlook is encouraging, and the species makeup of Red River is a better situation than we usually can count on in montane streams.

An equally critical measure of the bottom fauna is based on gravimetric determinations, and our 1981 data may be compared with data taken on 12 previous visits to the Red River, as follows, expressed as grams of organisms per square meter of stream bottom.

Station	July 1981	Average of 12 previous site visits	Range for 12 previous site visits
1	26.5	3.0	0.4 - 7.3
1A	3.0	9.2	0.3 - 32.3
2	1.5	3.6	0.5 - 16.3
3	6.7	4.8	0.8 - 17.3
4	1.8	2.4	0.1 - 10.9
5	4.9	13.0	1.0 - 51.6
6	6.7	1.4	1.4
AVERAGE	7.3	5.2	0.6 - 19.6

Because of the many (quintuplicate) samples taken during the Red River investigations, the data in this table are quite significant. The wide variations from time to time and from station to station are typical of stream insect populations where individual species have their maxima and minima at widely different times and where the abundance of individuals within each species likewise varies from season to season and from year to year.

The data for Station 4, however, are not typical. This is Pope Creek, and the fact that it is periodically dry makes it difficult for a normal insect population to become established. As a result, the average density figures are low.

Stations 1A (Goat Hill) and 2 (Eagle Rock) are perrenial problems, and their reduced populations are undoubtedly due to the persistent compact deposits of fines derived from breaks in the slurry line. This is not a major faunal prolem, however, since small unpolluted montane streams sometimes are even less productive than these two stations on the Red River (see Pennak 1977).

As a whole, and aside from stations 1A and 2, the biotic situation in 1981 can be judged satisfactory and improving.

Lithophyton

The bottom film of living and dead organic matter forms much of the food material for insects, and in 1981 it was much more developed than it was during any previous visit made by the author, in the magnitude of two to four times greater. Our 1981 field work was done in July, and ordinarily this is a time when the lithophyton is still recovering from the scouring action of the spring runoff. Perhaps the unusual 1981 condition was the result of a generally drier spring and summer. Detailed lithophyton data are as follows, expressed as mg organic matter per 5-minute sampling period.

Station 1	414.6
1A	57.3
2	61.5
3	423.6
4	252.6
5	274.8
6	499.9

As might be expected, Stations 1A and 2 were the low producers, a reflection of the occurrence of compacted fines at these stations.

The species make up of the living fraction of the lithophyton was "healthy," consisting chiefly of an assortment of diatoms.

SUMMARY

On 18 and 19 July 1981 a monitoring visit was made to the usual sampling sites on the Red River. Collection of data and methodology were identical with those used in all previous work.

Upstream temperatures (stations 1, 1A, and 2) were several degrees higher than usual, perhaps because of low 1981 and hot weather.

The water was exceptionally clear at all stations.

The stream bed was clean and normal except at stations 1A and 2 where the fines (tailings) from previous breaks in the pipeline were compacted on the substrate between rubble near the shoreline. Even at these two stations, however, the situation was better than in previous years.

Bound carbon dioxide and hydrogen-ion concentration readings were similar to those of previous years. High productivity potential was indicated. The pattern of total dissolved solids was likewise unchanged except that Pope Creek water contained a high of more than 2400 mg per liter TDS. Nevertheless such water continued to have what appears to be a fertilizing effect on the Red River.

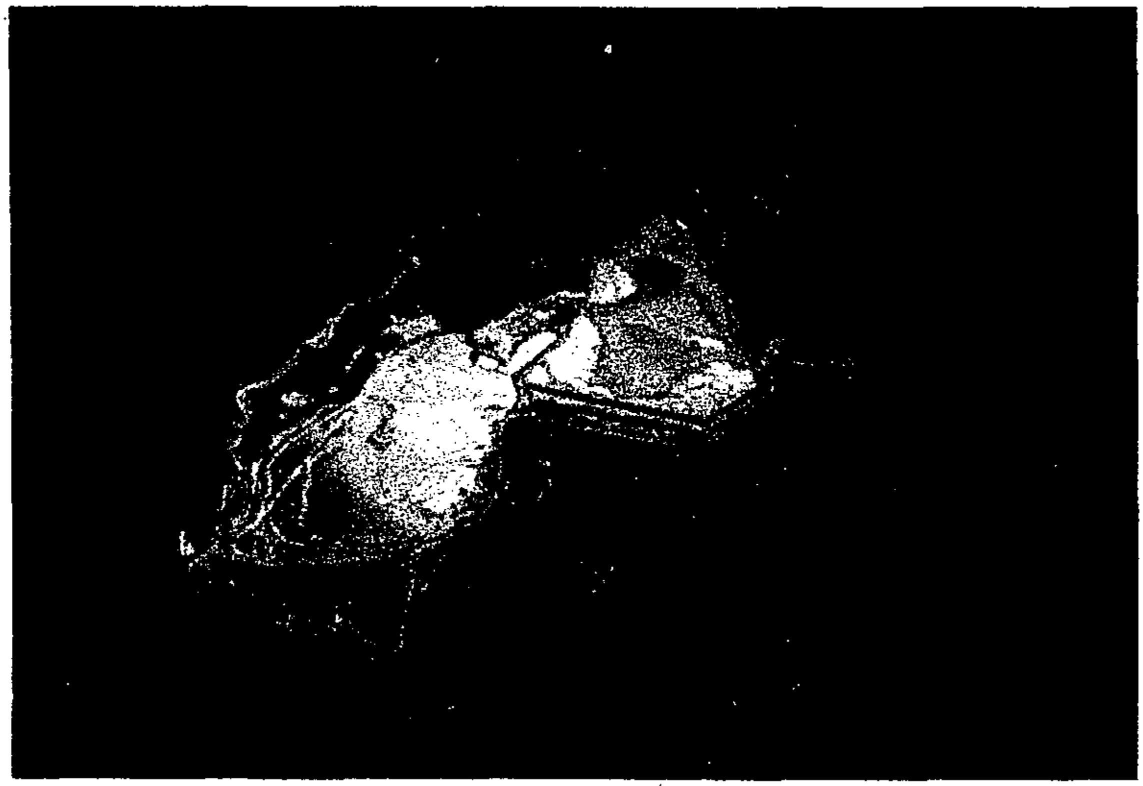
The bottom insect population showed improvement by the occurrence of longer lists of species collected. Gravimetrically, the Goat Hill and Eagle Rock stations had the lowest insect populations, as in the past, although there was improvement here also. Our July 1981 samples all averaged 7.3 grams of organisms per square meter. An average for all of the previous samples (dating back as far as 1971) was only 5.2 grams per square meter. The overall improvement is obvious.

The lithophyton (organic food source) on the rubble of the Red River was in excellent condition in 1981, - much higher than at any previous visit.

Even though our 1981 data are based on a single visit to the Red River, it is clear that the stream is now in better biological shape than it was at any previous time when the author visited the area.

Report No. 052010/1

WATER AND CHEMICAL LOAD BALANCE FOR QUESTA TAILINGS FACILITY, QUESTA, NEW MEXICO



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WATER AND CHEMICAL LOAD BALANCE FOR QUESTA TAILINGS FACILITY, QUESTA, NEW MEXICO

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WATER AND CHEMICAL LOAD BALANCE STUDY FOR QUESTA TAILINGS FACILITY, QUESTA, NEW MEXICO

1 INTRODUCTION

1.1 Terms of References

On September 21, 1999, Molycorp Inc. filed an application with the Mining and Minerals Division (MMD) of the Energy, Minerals, and Resources Department of New Mexico for extension of time for approval of a closeout plan for the Questa Mine, New Mexico, under Permit No. TA001RE. As part of this extension request, Molycorp submitted a schedule for milestones and deliverables for the period December 1999 until anticipated approval of the Closeout Plan. On January 31, 2000 Molycorp submitted a work plan for a Comprehensive Hydrological Balance Study (Task A.11 of Work Schedule for Mine Site and Task A.3 of Work Schedule for Tailings Facility). This report summarizes the results of task 4 of the above referenced work plan entitled "Load Model for Tailings Area.

1.2 Study Objectives

The objectives of the present study are as follows

- Develop an annual water balance for the Questa tailings facility for the period 1966-1999 (i.e. the entire life of operation);
- Develop an average annual load balance for selected constituents (sulfate, molybdenum, fluoride and manganese) covering the life of the facility (1966-1999).

1.3 Structure of Report

This report presents the results of a study on water balance and chemical load balance for the Questa tailings facility near the town of Questa, Taos County, New Mexico. Section 2 introduces the tailings facility and provides background on the historical tailings construction and water management. Section 3 provides a brief synopsis of the current understanding of the groundwater system underlying the tailings area. In section 4 the historical tailings deposition is reconstructed. In section 5 climatic and hydrological factors relevant to the water balance (evaporation, yield etc.) are derived. The water balance analysis for the tailings facility is described in Section 6. Finally, the load balance analysis is presented in section 7

2 BACKGROUND

Molycorp's Questa Division owns and operates a large tailings facility located near the town of Questa, New Mexico (Figure 1). Over the last 33 years a total of nearly 100 million tons of tailings from the Questa Molybdenum Mine have been discharged into this facility covering a total surface area of about 260 ha (640 acres) (as of 1997). The tailings originate from a hydrothermally altered molybdenum porphyry deposit of volcanic origin. After crushing and grinding the ore is extracted using froth flotation while the tailings are buffered to about pH 8.5 by adding lime and are pumped to the tailings impoundment in a pipe line.

The tailings are impounded in two deeply incised valleys (so-called "arroyos") behind two major earth fill dams (Dams 1/1C and Dam 4, respectively) (Figure 1). Currently, tailings are discharged behind the smaller Dam 5 in the northwestern corner of the facility. The tailings facility lies in an alluvial plain at an elevation of about 7600 feet a.m.s.l., bordered by the Sangre de Cristo Mountains to the east and the Guadalupe Mountains to the west. To the south, the Red River and its tributary, Cabresto Creek, have cut a prominent valley 100 to 200 feet below the level of the alluvial plain (Figure 1).

2.1 History

The purpose of this section is to provide an orientation to the Molycorp tailings impoundment and to briefly outline the sequence of dam construction from the commissioning of the facility in 1965 to the present. For a more thorough discussion of the tailings impoundment history, particularly relating to the geotechnical aspects of the various dams, the reader is referred to RGC Report 052004/1 entitled "Questa Tailings Facility Revised Closure Plan" (RGC, 1998).

The tailings impoundment was created by the construction of dams across two ephemeral tributaries of the Red River located west of the Town of Questa. These two tributaries, known as arroyos, are adjacent to one another and are oriented in a southwest direction. Figure 2a shows the tailings impoundment in relation to the Red River, the Town of Questa, and the Guadalupe Mountain. Figure 2b is a schematic that emphasizes the main features of the tailings impoundment, particularly its dams and ditches. The two arroyos are unofficially named after the land-subdivision sections in which they are primarily located, namely Section 35 and Section 36. Table 1 provides a chronological listing of the construction sequences involved in developing the dams shown on Figure 2b.

Development of the tailings impoundment was initiated in 1965 with the construction of a starter dam across the Section 36 arroyo at a site some 0.7 miles above the Red River. This dam (designated Dam 1) was subsequently raised a total of five times, with the last raise occurring in 1971. In 1969, Dam 2 was constructed about one mile upstream of the first dam. The purpose of this second dam was to contain the tailings deposit from advancing onto property that, at the time, was not owned by the mine.

In 1971, the tailings impoundment was expanded to the neighbouring arroyo. This was accomplished by constructing a starter dam across the Section 35 arroyo at a location about 0.45 miles above the Red River. This dam, known as Dam 4, was subsequently raised a total of five times in the years 1972, 1973, 1975, 1980 and 1982. In 1973, Dam 3A was constructed about one mile upstream of Dam 4 to contain the tailings deposit on its north side. This dam was not extended completely across the valley, so as to allow for the continued operation of a decant channel excavated into the western valley slope of the Section 35 arroyo. The role of this particular channel is discussed later.

In 1975 the storage capacity of the Section 36 arroyo was increased substantially with the construction of a number of new dams. Instead of raising Dam 1, a new structure was constructed on the deposited tailings approximately 1200 feet north of the Dam 1 crest. This new structure, labelled Dam 1C, was oriented parallel to Dam 1. To provide containment on the east side of the tailings deposit, Dams 1B and 2A were created. As can be seen from Figure 2b, Dam 2A was extended to the north of the east abutment of Dam 2, thus opening up the northern portion of the arroyo for tailings deposition. Because of this northern extension of the impoundment, Dam 2 was eventually buried by the tailings deposit. Some tailings have been deposited in a small area to the east of Dam 1B. This deposition took place prior to the 1975 expansion and required that a portion of Dam 1B be constructed on tailings.

In 1980, a cyclone berm was raised several hundred feet upstream of Dam 2A. Then, in the period 1981 to 1982, Dams 1C, 1B and 2A were raised to their present crest elevation. Also in this period, a separator dike was constructed on the ridge between the Section 35 and 36 arroyos, extending north from the west abutment of Dam 1C.

In 1990, the area north of Dam 3A was opened up to tailings deposition by constructing Dam 5A across an old decant channel. The eastern abutment of this dam joins to the northern face of Dam 3A. Dam 5A was raised in 1996 to its current crest elevation.

Figure 3 presents the annual record of tailings production deposited in the Molycorp tailings impoundment. By the end of 1999, tailings production had reached a total of 102 million tons of tailings.

2.2 Water Management

The Molycorp mill is located on the northern bank of the Red River some 8 miles upstream of the tailings impoundment. Tailings slurry produced by the mill is delivered to the impoundment via a series of pipelines. The slurry typically comprises 38% solids and 62% water by weight.

During much of the facility's life, an excess of water accumulated in the impoundment, which necessitated making surface releases to the Red River. During the first four years of operation, a clarification pond was maintained at the upstream face of Dam 1. Excess water was decanted from this pond, diverted under the dam via two decant conduits, and then conveyed to the Red River by a ditch.

In 1970, the decant arrangement was significantly modified. The clarification pond was shifted to the north near Dam 2 and the two decant conduits running below Dam 1 were plugged with concrete. Excess water was then made to overflow a weir structure located in the bank alongside Dam 2. This water was then conveyed along a series of two ditches to a small holding pond called Pope Lake at the south end of the Section 35 arroyo. The first ditch was excavated through the ridge separating the two arroyos. The second ditch (known as the West Decant Channel) was constructed along the western valley slope of the Section 35 arroyo. From Pope Lake, the water passed through a culvert and on to the Red River. Eventually, the culvert was replaced with a Parshall flume to allow the decant flows to be measured. The outlet of Pope Lake is known as Outfall 001 in the mine's NPDES permit. When the Section 35 arroyo was developed as a repository for tailings, the excess water from this part of the impoundment was released into the West Decant Channel to join the flow from the Section 36 arroyo.

In 1975, a seepage barrier system was constructed to intercept seepages observed at the toe of Dam 1 and along the eastern slope of the ridge separating the Section 35 and Section 36 arroyos. A system of pipes was installed to convey the collected seepage directly to the Red River. The EPA designation for the discharge point of this system is Outfall 002. This system has evolved over the years with the addition of extraction wells and new seepage barriers. For further details, the reader is referred to the closeout plan for the tailings impoundment (RGC, 1998).

Also in 1975, two drainage channels were constructed around the perimeter of the tailings impoundment for flood control. These run along the western and eastern sides of the impoundment and command basins of 3400 acres and 770 acres, respectively.

In 1983, an ion exchange water treatment plant was constructed alongside Pope Lake to process decant water (if any) before being discharged to the Red River.

3 SUMMARY OF GROUNDWATER STUDIES

Molycorp has commissioned several studies over the years to investigate groundwater conditions in the vicinity of the tailings impoundment (Dames and Moore, 1987; Vail, 1988; Vail, 1993; SPRI, 1993, 1994 & 1995; RGC, 1997). The results of these hydrogeological studies are summarized in a recent publication by Wels et al. (2000) which is cited below:

Figure 4a shows an idealized geological cross-section running east-west with observed water levels immediately downstream of the Questa tailings facility. As a first approximation, the local groundwater system can be divided into an upper (shallow) aquifer system (above an elevation of ~7200 ft) and a lower (deep) aquifer system (below an elevation of ~7200 ft). The shallow aquifer system consists of a complex mixture of recent alluvial sediments, ranging from coarse, permeable sand and gravel units to very low permeable clay layers resulting in very high spatial heterogeneity at the local scale. The deep aquifer system consists of deep alluvial sediments in the eastern parts and volcanic rocks from the Guadalupe Mountains in the western parts of the study area (beneath the Dam 4 arroyo) (Figure 4a). The volcanics have a very high secondary permeability (in the order of K=1x10-3 m/s) and act as a drain for shallow groundwater flowing above in the shallow alluvial sediments (Figure 4a).

Most of the recharge to the groundwater system probably occurs from ephemeral and perennial streams (and related irrigation ditches) running off the Sangre de Cristo Mountains, which upon leaving their mountain courses and entering the plateau area, lose much of their flow to permeable alluvial sediments. Other sources of recharge are leakage from arroyo flood flows, and infiltration of water pumped for irrigation. Recharge from local precipitation is comparatively small (<25–50 mm/yr). Recharge to the volcanics occurs predominantly though leakage from the overlying alluvial sediments.

A regional groundwater flow model was constructed and calibrated using borehole logs, observed water levels and measurements of accretion and springs flows to the Rio Grande and the Red River (see RGC Report 0052002/1 for details). The calibrated regional model provided defensible model boundaries for a local groundwater flow model, which was used to estimate the volumes of groundwater flowing beneath the tailings facility (RGC 1997). Figures 4b and 4c show the simulated water level contours in the shallow and deep aquifer system, respectively. The calibrated flow model suggested that about 2/3 of the tailings seepage from the Dam 1/1C impoundment would recharge into the shallow aquifer system. The underflow of shallow groundwater beneath the Dam 1/1C impoundment is estimated to be about 60 l/s (2.1 cfs). The shallow groundwater flows in a southwesterly direction and discharges near the Red River ("cold springs") (Figure 4b). In contrast, tailings seepage from the Dam 4&5 impoundments would recharge directly into the deep volcanic aquifer. The underflow of deep groundwater beneath the Dam 4/5 impoundment is estimated to be about 153 l/s (5.4 cfs). The deep groundwater travels in a westerly direction beneath the tailings impoundments and assumes a south-westerly direction upon entering the volcanic aquifer, eventually discharging in the Red River Canyon ("warm springs") (Figure 4c).

4 RECONSTRUCTION OF TAILINGS DEPOSITION

4.1 Purpose and Method

The history of tailings deposition was reconstructed for three purposes:

- to provide a means of assessing the volume of water stored in the voids of the deposited tailings;
- to simulate how the footprint of the tailings impoundment increased from 1965 to 1999 (to set an upper limit on the size of the wetted area that was subject to evaporation losses); and,
- to develop a general understanding of the sequence of dam construction used to create the tailings impoundment.

The reconstruction entailed two broad tasks. The first was to establish the elevation-area-capacity (EAC) curves for the Section 35 and Section 36 arroyos. The second task was to create a spreadsheet mass balance that could be used to simulate the historical deposition of tailings into the two arroyos. These two tasks are described below under separate headings.

4.2 Elevation-Area-Capacity Curves

The development of the EAC curves involved performing the following six steps:

1. assemble a map showing the pre-mining topography of Sections 25, 35 and 36;
2. on this map, draw contours representing the upstream faces of all the dams used to contain the deposited tailings;
3. outline the enclosed contours formed by the intersections of the pre-mining topography and the superimposed contours of the dam faces;
4. measure the planimetric area of the enclosed contours;
5. use the trapezoidal rule to compute the incremental storage volumes between successive contour intervals; and,
6. accumulate the incremental volumes to create a relationship between elevation and storage.

The resulting relationships between elevation, area and storage volume are tabulated in Appendix A. It is interesting to note that, not one, but two EAC curves were required for each arroyo in order to represent the conditions that existed over the entire period from 1965 to 1999. This was a consequence of the way in which the northern portions of the arroyos were developed. For example, tailings deposition in Section 36 was originally constrained from advancing to the north by the construction of Dam 2. In 1975, a new dam was constructed north of Dam 2, thus opening up the intervening area to tailings deposition. The inclusion of this new area required that a second EAC curve be generated to represent the expanded geometry of the tailings impoundment.

A similar set of circumstances occurred in the Section 35 arroyo. Up to and including 1990, Dam 3A was used to contain the tailings deposit on its north side. With the construction of Dam 5A, the area north of Dam 3A was made available for tailings deposition. This again required the specification of a new EAC curve to represent the expanded depositional area.

Two points should be noted about the EAC curves:

- They were derived using a topographic map with 50 ft contours. Although fairly course, these contours were judged to provide adequate accuracy for the purpose of reconstructing the historical water balance.
- In constructing the EAC curves, no explicit allowance was made for increased storage capacity resulting from the excavation of borrow sites within the tailings impoundment area. As discussed in the next section, it was necessary to make a small adjustment to the original EAC curves. This adjustment could be interpreted as an indirect means of accounting for the borrow areas.

4.3 Filling History

The following key information, in addition to the EAC curves, was employed in reconstructing the depositional history of the two arroyos:

- dry density of deposited tailings ($M_S/(V_V + V_S)$);
- specific gravity of the tailings solids (G_S);
- water content of saturated, deposited tailings (M_W/M_S);
- annual production record of tailings for the period 1966 to 1999; and,
- spot measurements of the average elevation of the tailings surface.

Where: M_S is the mass of solids

V_V and V_S the volume of voids and solids respecitively and

M_W is the mass of water.

All of the above information was synthesized into a spreadsheet that simulated the filling of each arroyo with tailings. The spreadsheet was designed to perform the following six functions for each of the 34 years from 1966 to 1999:

- distribute the annual tailings production (tons) between the Section 35 and Section 36 arroyos;
- keep track of the accumulated tonnage of tailings in each arroyo;
- using the dry density, convert the accumulated tailings tonnage to an equivalent deposited volume (or bulk volume);
- using the specific gravity, determine how much of the deposited tailings volume was occupied by tailings solids and how much was occupied by void space (which can be filled with water or a combination of water and air);
- using the EAC curves, determine the average surface elevation of the deposited tailings in each arroyo; and,

- using the EAC curves, determine the total footprint area of the tailings deposit.

By incorporating the above functions, the spreadsheet provided an internal check on its calculations. This internal check was the consequence of using two independent methods for estimating the total volume occupied by the deposited tailings. The first method used two sets of data: (i) the record of tailings production; and (ii) laboratory measurements of density made on tailings samples collected from boreholes drilled into the tailings deposit. The quotient of tailings tonnage to average density provided the estimate of bulk volume. Table 2 summarizes the geotechnical data required to implement the first estimation method.

The second means of assessing the tailings volume involved using the prepared EAC curves and a set of periodic surveys of the average surface elevation of the tailings deposit. In effect, this method involved doing a numerical integration to determine the volume of space between the bottom surface of the tailings deposit and the top surface of the deposit.

The two independent methods provided comparable results. However, there was enough of a discrepancy that adjustments were warranted. The following three options were considered for making the adjustment:

- accept the original estimate of dry density (92 lb/ft^3) as accurate and adjust the EAC curves to fit (which would involve increasing all of the incremental volumes in the EAC curves by a factor of 1.08);
- adopt a dry density of 94.7 lb/ft^3 (based on Geocon's average assessment of the saturated water content of 28.2%) and adjust the EAC curves to fit (which would involve using a reduced scaling factor of 1.05); or,
- accept the original EAC curves as accurate and adjust the dry density to fit (which would require adopting a value of 99 lb/ft^3).

Both of the independent methods have some uncertainty associated with their estimates. In recognition of this, the second option was selected so that slight adjustments were made to both techniques. Figure 5 presents the results obtained from the spreadsheet after making the required adjustments. The top plot on this figure shows how the tailings volume increased in the Section 36 arroyo from the commissioning of Dam 1 (1966) to the present. The bottom plot provides similar information for the Section 35 arroyo. The top line on both plots denotes the bulk volume of tailings. This bulk volume is subdivided into its three components (i.e., the volumes occupied by solids, water and air). The method for determining how much of the tailings voids were occupied by air is described below in Section 6. The analysis indicates that the deposited tailings have a total volume of 79.8 million cubic yards, or 49,500 acre-ft. The estimated average porosity ($V_V/(V_V + V_S)$) is 43%.

The above discussion focussed on assessing the total volume of tailings in the Molycorp facility. The remainder of this subsection is devoted to explaining how this total tailings production was distributed between the two arroyos. Basically, this was done using a trial and error approach. The following four items were used to guide the approach:

- record of how the highest crest elevation on the dams changed with time from 1965 to 1999;
- the year in which tailings deposition was initiated in each of the two arroyos;

- spot reports of how the tailings were apportioned between the two arroyos (obtained from inspection reports for the tailings impoundment); and,
- some measurements of the average overall tailings surface elevation (extracted from maps of the impoundment and various design reports).

While all four of these items provided clues as to how the tailings production was apportioned, the first item was by far the most important. Two reasons exist as to why the record of highest dam crests proved invaluable. Firstly, it provided an upper limit on how high the average tailings surface could be at any one time in each of the two arroyos. Secondly, the record indicated episodes when the dams in the two arroyos had recently been raised. A reasonable assumption was made that the greater proportion of a given year's tailings production should be deposited in the arroyo which experienced the latest raise to its system of dams (i.e., most of the tailings should be placed in the impoundment with the greater amount of unfilled storage capacity). Figure 6 shows the plots used to implement the apportionment technique. The top plot displays the simulated average tailings surface elevation as a function of year for Section 36. The bottom plot provides the same information for Section 35. Dashed lines are superimposed on both plots to mark how the dam crest elevations changed with time. As can be seen, the estimated tailings levels remain always below the crest elevations.

Based on the analysis above, the Section 36 arroyo holds approximately 47.3 million cubic yards of bulk tailings (59%) while the other arroyo contains the remaining 32.6 million cubic yards (41%). In terms of mass, the estimated split is 60.4 million tons and 41.6 million tons, respectively.

5 CLIMATE AND HYDROLOGY ANALYSES

5.1 Objectives and Method

Preparation of the water balance required an understanding of four components of the hydrological cycle, namely: precipitation, evaporation, runoff yield and groundwater. This section describes the steps undertaken to quantify the first three components. The assessment of groundwater conditions has been the subject of a number of investigations over the years, including the development of a numerical model for the tailings area (see section 3). Based on a review of all available data these earlier estimates of groundwater flow were used to complete the present water and load balance study.

5.2 Precipitation

The precipitation regime of the tailings impoundment was characterized using a long-term climate record collected at the community of Cerro (NWS Station 291630). This station has been relocated a number of times throughout its history to different parts of Cerro. Its current location, where it has been since August 1978, is some 3.5 miles north of Dam 1 at an elevation of 7650 ft.

The data collected at this station were subjected to two types of processing. Firstly, estimates were made for missing data in the daily record (a process known as "patching"). The record begins in 1946 but the data patching was restricted to the period 1959 to 1999. Over this period, most of the breaks in the record were only for short periods of 2 days or so but some spanned several weeks. Overall, the record was found to be 96.1% complete. Estimates for the missing data were obtained from the precipitation record of the Town of Red River, located about 12 miles to the east of Cerro. The Town of Red River is at a higher elevation so the precipitation values had to be scaled before being entered into the Cerro record. The scaling factor adopted was the ratio of the mean annual precipitation (MAP) at Cerro to the MAP at Red River, which worked out to approximately 60%. After the patching was complete, the daily values were accumulated to create an annual precipitation record for Cerro.

The second processing step was to check the consistency of the record (i.e., to determine whether the record had any systematic errors due to a change in instrumentation, gage location, or some other cause). This was accomplished by preparing a double-mass plot using the data from the Town of Red River as a base (see top plot on Figure 7). This plot revealed that the Cerro record indeed had a systematic error. The period from 1979 to 1999 was receiving relatively more precipitation than the earlier period. It is noteworthy that the kink in the double-mass plot coincides with the date of the latest relocation of the Cerro gauge. This suggests that the new location receives slightly more precipitation, on average, than the old location. The annual precipitation values for the period 1960 to 1978 were scaled by a factor of 1.16 to make them consistent with the values of the more recent period. Using the patched and consistent precipitation record, the MAP for Cerro works out to 13.6 inches.

Two points should be noted about the double-mass analysis:

- The possibility existed that the inconsistency was not in the Cerro record but rather in the Red River record. To test this possibility, a double-mass plot was created between the data of Red River and Eagle Nest (located some 23 miles southeast of Cerro). This plot (see bottom graph on Figure 7) suggests that the Red River record is consistent and the problem did, in fact, lie with the Cerro record.

- The double-mass plot identifies only systematic errors in the precipitation record and not long-term wet and dry cycles in the climate. This is because both the station being checked (Cerro) and the station being used as a base (Red River) would be similarly affected by the climate cycles.

5.3 Evaporation

Two rates of evaporation were of interest, namely lake evaporation and evapotranspiration. The former refers to evaporation from a free-water surface while the latter refers to evaporation from a land surface, including transpiration from vegetation. Both rates were estimated using a computer model known as WREVAP, which was developed by Environment Canada's National Hydrology Research Institute (NHRI, 1985). The lake evaporation component of the model has been tested against the results of detailed water-budget estimates for 11 lakes in North America and Africa. The evapotranspiration component, on the other hand, has been tested against the long-term water-budget estimates for 143 experimental river basins in North America, Ireland, Australia and New Zealand (Morton, 1983).

The meteorological inputs to the WREVAP model comprise humidity, air temperature and global solar radiation (or sunshine duration). Of these three factors, only temperature is measured in the near vicinity of the tailings impoundment (i.e., at Cerro). This precluded using the model to obtain a direct estimate of evaporation for the tailings impoundment. Instead, the model was used to estimate lake evaporation and actual evapotranspiration at climate stations in the general region. Observed trends in the estimated evaporation rates at these regional stations were then extrapolated to the study area.

Three climate stations, located at Albuquerque, Alamosa and the Molycorp mill site, were identified as candidates for the analysis outlined above. The first two are long-term stations operated by the National Weather Service. The third station was established by Molycorp in December 1995 and has operated ever since, with only a few small gaps of missing data. Figure 8 displays the results of applying the WREVAP model to the meteorological conditions at the three stations. The top graph shows estimates of mean monthly lake evaporation while the bottom graph shows the monthly distribution of actual evapotranspiration.

The estimated average annual lake evaporations at the three stations ranged from 40 inches to 57 inches. An examination of Figure 8 suggests that lake evaporation tends to decrease with elevation. Given this trend, the evaporation estimate for Alamosa of 46.5 inches was used to represent the evaporation conditions at the tailings impoundment. The elevation of this station (7536 ft) is virtually identical to that of the tailings impoundment (approx. 7500 ft).

The estimated average annual evapotranspiration rates were 6.9, 15.0, and 16.2 inches, respectively, for Albuquerque, Molycorp mill site and Alamosa. In contrast to lake evaporation, elevation is a poor predictor of evapotranspiration rates. Water availability (i.e., precipitation plus irrigation) appears to be a better predictor. Insufficient information was available to quantify the relationship between annual evapotranspiration and water availability. However, it is likely that the evapotranspiration rate for the tailings impoundment lies between the values estimated for Albuquerque (6.9 inches) and the mill site (15.0 inches).

Pan evaporation data collected in the region were used to partially validate the results obtained from the WREVAP model. As well as estimating lake evaporation and evapotranspiration, this model also assesses pan evaporation rates. Figure 9 is a comparison of WREVAP-estimated pan evaporation rates with observed pan evaporation rates. As can be seen, there is close correspondence between the two sets of values, especially when the dependency of evaporation on elevation is factored in. As a check on the WREVAP-estimated lake evaporations, the observed pan data from Santa Fe were adjusted using a typical pan factor of 70% and then plotted on the top graph of Figure 8. The adjusted pan values lie very close to the computed lake evaporation values for Alamosa. Given that the Santa Fe climate station is located at a similar elevation as the tailings impoundment (7200 ft vs 7500 ft), this close correspondence between the adjusted pan values and the WREVAP lake estimates suggests the adopted lake evaporation values for the tailings impoundment are accurate.

5.4 Yield

Yield refers to the portion of precipitation falling on a basin that subsequently contributes flow to the local stream network. In other words, it is the portion of precipitation not evaporated. The yield makes its way to the local streams via two routes: overland and through the groundwater system. The relative importance of these two routes varies from basin to basin and largely depends on the climate and the basin geology. The tailings impoundment is in a semiarid region and overlies permeable rock types. Accordingly, during most years, the yield is delivered to the stream network almost exclusively through the groundwater system. This statement is supported by an observation made about the two diversion channels constructed around the tailings impoundment. With the exception of small, intermittent inflows to the East Drainage Channel from irrigation ditches, the two diversion channels show no evidence that they have ever carried runoff over the 25 years they have been in place (Vail, pers. Comm.).

No direct measurements exist of the yield from the five tailings impoundment sub-basins. Obtaining such measurements would virtually be impossible owing to the fact that the yield is conveyed exclusively through the groundwater system during most years. In the absence of direct measurements, the yield was assessed using a flow-estimation technique developed by the USGS for the Taos Plateau (Hearne and Dewey, 1986). The Taos Plateau experiences similar hydrological conditions as the tailings impoundment area (i.e., a small yield that is usually conveyed exclusively through the groundwater system). Furthermore, no direct measurements of yield are available. To compensate for this lack of direct measurements, the USGS estimated the yield of the Taos Plateau from the experience gained at dry basins located elsewhere in New Mexico. For their analysis, the USGS assembled streamflow data from a total of 16 gauged basins. All of these basins resembled the Taos Plateau because they received a small annual precipitation. However, the basins differed in that they overlaid rocks of low permeability. The USGS made the assumption that the measured flows at the outlets of these basins represented the total basin yield (i.e., groundwater bypass under the gauging station was assumed to be negligible, based on the impervious nature of the basins).

The USGS transferred the data from the 16 basins to the Taos Plateau using a multiple regression of mean annual water yield against three independent variables: mean winter precipitation, channel slope, and drainage area. This technique was meant to assess the runoff from a whole basin and not its component subbasins. Because of this, it proved difficult to directly apply the technique to the subbasins outlined for the tailings impoundment, particularly Subbasins 2, 4 and 5 which do not include headwater areas. For these three subbasins, some uncertainty existed as how to define representative channel slopes and drainage areas for input to the multiple regression equation. To get around this problem, the USGS technique was modified so that mean winter precipitation was the only independent variable in the regression analysis. As it turns out, mean winter precipitation is the most important of the three variables in explaining the variation in annual yield amongst the 16 USGS basins. Figure 10 is a graphical representation of the modified USGS technique. The vertical axis shows values of mean annual runoff (i.e., yield) expressed as an equivalent depth of water. The horizontal axis shows values of mean winter precipitation, with the winter being defined as the 7-month period from October to April. Given an average winter precipitation at Cerro of 5.3 inches, the relationship indicates the average yield of the tailings impoundment subbasins is approximately 0.4 inches.

The estimated average annual evapotranspiration values for Alamosa and the Molycorp mill site provide partial verification that this yield value is reasonable. Given an average annual yield of 0.4 inches and a MAP of 13.6 inches (Cerro), the average annual evapotranspiration rate for the tailings impoundment area would be 13.2 inches. This compares well with the 15.0 and 16.2 inches estimated for, respectively, the Molycorp mill site and Alamosa. Both of these sites would be expected to have somewhat higher evapotranspiration rates. The mill site is located in a slightly wetter area and Alamosa, although having a lower MAP than Cerro, is located in a region of extensive irrigation. An annual evapotranspiration rate of 13.2 inches is equivalent to about 28% of the estimated average annual lake evaporation rate for the tailings impoundment.

6 WATER BALANCE ANALYSIS

6.1 Study Area

The first task in setting up the water balance was to define the boundaries of the study area. For many tailings impoundments, this involves outlining a limited area located above the tailings dams and below the diversion ditches. For the Molycorp facility, however, such an area was judged to be too small because it would not adequately account for the large aquifer system underlying the tailings impoundment and, in particular, would not include the points of groundwater discharge from this system. To help define a suitable study area, reference was made to a recent and comprehensive investigation of the groundwater conditions in the vicinity of the tailings facility (RGC, 1997). This investigation examined the groundwater conditions at a regional scale and subsequently at a smaller, local scale (see section 3). In both cases, a numerical model was developed to represent the groundwater system. Both models were calibrated against water table readings and observed groundwater discharges (i.e., springs and accretion rates to the local streams). One of the objectives of the regional groundwater model was to examine the coarse details of the regional aquifer system and to determine possible migration routes for seepage from the tailings impoundment. This model demonstrated that all such seepage would eventually migrate to the Red River and no portion would follow a route through the Guadalupe Mountains to the Rio Grande. Furthermore, this model indicated that seepage-affected groundwater would discharge in the reach of the Red River between the Highway 3 bridge and a point just downstream of the State Fish Hatchery (see Figure 4c). The local groundwater model was set up to focus on the part of the groundwater system that discharged in this reach of the Red River. Its boundaries were defined using results obtained from the regional groundwater model.

The boundaries of RGC's local groundwater model were adopted to represent the groundwater portion of the tailings impoundment water balance. Figure 11 shows these boundaries superimposed on a map of the general area. The Red River forms the southern boundary while Cabresto Creek forms part of the eastern boundary. The remainder of the eastern boundary is formed by a constant head boundary, which parallels the 7480 ft head contour of the regional phreatic surface. The western and northern limits of the local groundwater model are defined by no-flow boundaries.

With the groundwater portion of the water balance defined, the next requirement was to specify the study boundaries at the ground surface. Given that infiltration from the surface is one component of the flow in the groundwater system, it was desirable to define a study area that substantially overlapped the outline of the local groundwater model. Figure 11 shows the selected outline. The southern boundary was made to coincide with the stream channel of the Red River. The western, northern and eastern boundaries were defined by topographic divides.

6.2 Conceptual Representation

With the study area defined, the next task was to conceptualize the tailings impoundment as a system of interlinked components. Components can be thought of as physical features that exert some influence on the storage and/or movement of water. Two types of components were adopted, subbasins and groundwater aquifers. For the former type, the total study area was subdivided into 5 subbasins, as dictated by the locations of dams and diversion channels (see Figure 2a). Two of the latter type of component were selected, a shallow aquifer and a deep one. Details on these aquifers are discussed later.

Figure 12 shows how these components were organized into a conceptual representation of the tailings impoundment and its adjoining areas. This figure comprises two flowsheets, one for the ground surface and the other for the underground. Boxes on these flowsheets symbolize the two types of components. Subbasins are used exclusively in the first flowsheet and aquifers in the second. Numbers in the upper, left-hand corner of the "subbasin" boxes correspond to the Subbasin ID Nos. used in Figure 2a.

Lines and arrows on the flowsheets depict the movement of water between the components. Dashed lines represent flows that occur exclusively through the ground. Wavy lines depict an evaporation loss. Straight, solid lines cover all other types of flux, including precipitation and discharge from the tailings lines. Numbers on the lines denote the average annual flow in cubic feet per second. Storage changes within the components are signified by bracketed numbers within the boxes.

The final symbol used on the flowsheets is a circle with an enclosed letter. These are tabs to show how the two flowsheets are interconnected. They specify either of two types of flow, infiltration from the surface to groundwater or discharge from the groundwater system.

The subsections below describe how the flows for the various flowlines were quantified.

6.3 Liquid Fraction of Tailings Slurry

Molycorp maintains a detailed record of the volume of water sent down the tailings lines to the tailings impoundment. This water is derived from a number of sources: abstractions from a weir in the Red River; abstractions from wells developed in the Red River valley fill; ore moisture; and, mine dewatering. The flow measurements for these sources are recorded on a standardized data form known as the "Plant Water Report" and submitted to the State Engineer Office. Vail Engineering used these forms to compile a monthly record of the total water diverted from the mine site to the tailings impoundment via the tailings lines. Their record spanned the period January 1966 to September 1993. As part of the present study, this record was updated to the end of 1999.

These diverted flows can not be strictly defined as the "liquid fraction of the tailings slurry" because water is also sent down the tailings lines during periods when tailings are not being produced by the mine. Over the life of the impoundment, two main reasons have existed for delivering this extra water to the impoundment. Originally, this water was used to maintain ponds on the tailings impoundment during mine shutdowns for the suppression of dust. In recent years, the need for this water has subsided because the problem of blowing dust has largely been mitigated by covering the tailings surface with an interim soil cover and vegetation. Presently, the main reason for continuing the diversion of water is to provide a means of improving the water quality in the stretch of the Red River between the mine and the Ranger Station. This is achieved by pumping water from wells located at the mill site and then diverting this water to the tailings impoundment. This has the effect of removing heavy metals and other naturally occurring contaminants from the alluvium in the Red River valley that would otherwise eventually discharge to the surface waters of the Red River at downstream locations. The heavy metals contained in the water pumped from the mill site wells are derived from sources upstream, and not related to, the Questa mine development. The relative importance of this pumping on reducing chemical concentrations in the Red River will be investigated in other studies related to the preparation of the Closeout Plan for the mine (see RGC Report 052008/2 entitled "Workplan for Comprehensive Water and Load Balance Study, Questa Mine, New Mexico").

The monthly record of flows diverted to the tailings impoundment is complete for the period 1966 to 1999, with the exception of the first nine months in 1996. During this period, the mine was in a temporary shutdown but was dewatering the underground mine in preparation for a reopening in October 1996. To patch the missing data in this period, the assumption was made that the only water being diverted down the line was that obtained from mine dewatering. Furthermore, the mine dewatering rate was assumed to remain steady at the rate observed in December 1995, or the month just before the nine-month break occurred in the record. Over the 34-year period from 1966 to 1999, the average flow rate was 5.8 ft^3/s, making this flow stream the largest component of the tailings impoundment water balance.

6.4 Decant

Over the life of the tailings impoundment, excess water that accumulated in the impoundment has been released to either of two ephemeral tributaries of the Red River. From the year that the tailings impoundment was commissioned (1966) to about mid-1970, excess water was released to the arroyo below Dam 1 (i.e., the most easterly of the two arroyos used to permanently store the mill tailings). These releases were made via two concrete decant conduits under Dam 1. Subsequently, these decant conduits were plugged and the releases were directed to the westerly arroyo below Dam 4 via the West Decant Channel and Pope Lake. Releases to the westerly arroyo are monitored at the outlet of Pope Lake. The official EPA designation given to this discharge point is "Outfall 001". No surface releases have been made from the tailings impoundment since June 1990.

Three different techniques were utilized to reconstruct the annual record of decant flows from the tailings impoundment for the period 1966 to 1999. These are described below under separate headings.

6.4.1 Measured Flows

Outflows from Pope Lake pass over a flow-measurement weir (known as a Parshall flume). The date of construction for this weir is unknown but, based on flow records obtained from the Molycorp files, precedes the year 1978.

The filing system of the Molycorp mine was searched to locate flow measurements for this weir. As indicated above, this search uncovered data as far back as 1978. Most of these data were obtained from the Discharge Monitoring Reports that Molycorp submitted as a requirement of their NPDES permit (No. NM0022306). The assembled record of flows for this weir has many gaps in it up until February 1985. After this date, however, the record is complete.

The measured flows were used to reconstruct the decant record from 1983 to present. In this period, data were missing for 7 months in 1984 and 1 month in 1985. For the purpose of the water balance analysis, these months were assumed to experience zero decant flows. The lack of information for these eight months does not have a substantial effect on the overall conclusions drawn from the water balance analysis. The reconstructed annual decant record is presented in Figure 13.

6.4.2 Sulfate Balance

As indicated above, direct measurements could only be used to quantify a portion of the historical decant record. Accordingly, indirect methods were sought to infill the rest of the record. For the period 1976 to 1982, the method adopted was a sulfate balance.

This technique could be used because, during the period August 1975 to December 1985, Molycorp operated an extensive water quality monitoring program in the vicinity of the tailings impoundment. From August 1975 to November 1976, water quality samples were taken on a daily basis. Through this period, very few samples were missed. Afterwards, the chemical analyses were performed on weekly composite samples. Sulfate data for the period June 1984 to February 1985 could not be located and, hence, the sulfate balance procedure could not be used to infill the eight months of missing flow data in the years 1984 and 1985, as mentioned in the subsection above.

A number of chemical constituents were sampled by Molycorp during the 1975 to 1985 period. Of these, sulfate was determined to be the most suitable for the flow-estimation technique based on its tendency to act as a conservative tracer (i.e., under many conditions, sulfate is only minimally affected by chemical and biological processes and, therefore, remains in the water column).

To apply the sulfate balance, sulfate concentration records were extracted from the Molycorp water quality database for the following monitoring stations:

- a point on the Red River upstream of the inflows from Outfall 001 (Red River at the Questa bridge);
- the outlet of Pope Lake (Outfall 001); and,
- a point on the Red River well downstream of the inflows from Outfall 001 where the river and decant flows would have had an adequate travel distance to become substantially mixed (Red River just above the State Fish Hatchery).

The sulfate balance examined three distinct streams of water: 1) the discharge from Outfall 001; 2) all of the Red River flow above the fish hatchery except that portion originating as discharge from Outfall 001; and, 3) the combination of the these two streams. In total, these three streams presented six variables that had to be dealt with by the sulfate balance (namely, the three concentrations and the three discharge rates associated with the streams). The sulfate balance is, in effect, a combination of two equations and therefore can be used to estimate the magnitude of two of these variables, provided values are given for the other four. For the study at hand, the discharge rates of the first stream (Outfall 001) and the second stream (Red River excluding Outfall 001 flows) were treated as the unknowns. Accordingly, it was necessary to specify the concentrations for all three of the abovementioned streams and the discharge rate of the third stream (i.e., the total flow of the Red River just above the State Fish Hatchery).

Of the four "input" variables listed above, only two were directly measured, namely: the sulfate concentration of Outfall 001; and the sulfate concentration of the Red River above the fish hatchery. Some additional analyses were required to quantify the remaining two input variables. The top plot on Figure 14 illustrates the basis for estimating the sulfate concentration of that portion of the Red River water not originating from the Outfall 001 discharge. This plot shows how the sulfate concentrations varied in the Red River during 1976 at the Questa bridge and at a point just upstream of the fish hatchery. A bar graph over the top plot shows recorded periods when water was spilling from Outfall 001 (denoted by a thick black bar). As can be seen, the concentrations above the fish hatchery were very similar to those at the Questa bridge during periods of no discharge from Outfall 001. This observation provided the means of estimating the quality of that portion of the Red River flows not related to the Outfall 001 discharge. A comparison over the full period from August 1975 to December 1985 revealed that the sulfate concentration above the fish hatchery was about 10 mg/L greater than the observed concentration at the bridge during periods of no spill from Outfall 001. Accordingly, the quality of the Red River water without the influence of the Outfall 001 discharge was set equal to the observed concentration at the Questa bridge plus 10 mg/L. It is interesting to note that no trend was noted in the difference between the concentrations at these two monitoring points on the Red River over the period 1975 to 1985.

The fourth input variable to the sulfate balance, the total flow of the Red River above the fish hatchery, was estimated using streamflow data collected at USGS Station 08266820. This station was installed in the Red River below the fish hatchery in September 1978 and has operated continuously ever since. Two adjustments had to be made to this streamflow record in order for it be used in the sulfate analysis. Firstly, it had to be extended back to January 1976. This was done using a multiple linear regression with the streamflow data collected at two upstream gauging stations within the Red River basin (Station 08265000, Red River at the Ranger Station; and, Station 08266000, Cabresto Creek near Questa). Together, these stations monitor the bulk of the flow that passes by the gauging station below the fish hatchery. The flows estimated with the multiple linear regression are likely quite accurate based on the strong correlation achieved ($r^2 = 0.983$).

The second adjustment entailed transposing the streamflow record at Station 08266820 upstream to the Molycorp water quality monitoring point (i.e., to a point in the Red River above the fish hatchery). This was done by subtracting an estimate of the flow that enters the intervening reach of the Red River between the Molycorp monitoring point and Station 08266820. An estimate of the flow entering between these two locations was obtained from a detailed water quality survey conducted in April 1993 along the stretch of the Red River between the Questa bridge and the fish hatchery (Vail Engineering, 1993). The report documenting this survey describes the system of pipelines used by the fish hatchery to intercept spring water upstream of the fish hatchery. The water conveyed by this system constitutes the main inflow to the Red River in the intervening reach between the Molycorp water quality monitoring station and Station 08266820. In 1993, the pipeline system was reported to intercept an average flow of about 13 ft^3/s. For the purpose of the present study, this flow rate was assumed to remain sensibly constant throughout the year and to be representative of the conditions during the years 1976 to 1982. Accordingly, the Red River flows above the fish hatchery were set equal to the observed flow at Station 08266820 minus 13 ft^3/s.

With the four input variables specified, the flow at Outfall 001 was estimated using the following equation:

$$Q_{001} = Q_{D/S}\,(C_{D/S} - C_{U/S} - \Delta C)/(C_{001} - C_{U/S} - \Delta C)$$

where: Q_{001} = computed discharge from Outfall 001;

C_{001} = observed sulfate concentration of Outfall 001 discharge;

$Q_{D/S}$ = estimated flow of Red River above fish hatchery (set equal to observed flow at Station 08266820 minus 13 ft^3/s);

$C_{D/S}$ = observed sulfate concentration of Red River above fish hatchery;

$C_{U/S}$ = observed sulfate concentration of Red River at the Questa bridge; and,

ΔC = average increase in sulfate concentration between the two monitoring points on Red River during known periods when the flow at Outfall 001 was zero (approximately 10 mg/L).

Figure 14 graphically presents the results of applying the sulfate balance to the data for 1976. As already mentioned, the top plot shows the water quality of the Red River at locations above and below the inflow from Outfall 001. The middle plot shows the sulfate concentration of the Outfall 001 discharge, together with the estimated water quality of that portion of the Red River flows not originating from Pope Lake. Finally, the bottom plot shows the daily flows obtained by applying the above sulfate balance equation. Figure 13 presents the annual average flows estimated by the sulfate balance technique for the full period from 1976 to 1982.

6.4.3 Interpreted Flows

Neither measured flows nor sulfate balances could be used to establish the annual decant record for the years preceding 1976. For these early years, the decant flows had to be deduced using a set of plausible assumptions. In formulating these assumptions, recognition was given to the fact that the point of decant from the tailings impoundment was shifted from the Dam 1 arroyo to the Dam 4 arroyo (Outfall 001) in 1970. This shift probably corresponded with a significant reduction in the amount of water decanted. During the first four years of the impoundment's life, the water behind Dam 1 would have almost exclusively been overlying deposited tailings. Owing to the low hydraulic conductivity of the tailings, seepage losses would likely have been minimal. Accordingly, a substantial proportion of the inflows to the system (i.e., precipitation and the liquid fraction of the tailings slurry) would have been subsequently decanted from the tailings impoundment, via the decant conduits located under Dam 1.

To relocate the decant point to the Section 35 arroyo, the mine had to cut a decant channel through the ridge separating the Section 35 and Section 36 arroyos. Furthermore, another channel had to be constructed on the western valley slope of the Section 35 arroyo in order to convey the decant flows to Pope Lake. While travelling along these two channels, the decant flows probably experienced substantial seepage losses through the base of the channels, particularly considering that much of the channel alignment is over highly-permeable volcanic rock. As a result, the decant flows during the period 1970 to 1975 were probably less than the preceding period when excess water was decanted through the Dam 1 decant conduits.

Based on the above discussion, different approaches were necessary to estimate the decant flows for the periods 1966 to 1969 and 1970 to 1975. For the early period, an estimate was made of seepage losses through the tailings. Details of how this estimate was made are provided in Section 6.?. The continuity equation (I-O=ΔS) was then used to estimate the decant flows. In other words, the decant was set equal to the portion of the total inflows not consumed by evaporation, seepage, moisture retained in voids, and water stored in the clarification pond.

To estimate the decant flows during the period 1970 to 1975, reference was made to the level of decant during the succeeding period of 1976 to 1981. During both these periods the decant was directed to Outfall 001. Also, both periods were devoid of lengthy mine shutdowns. Based on these observations, the decant rates during the two periods were probably similar. The decant rate during the period from 1976 to 1981 was 20%, when expressed as a proportion of the total flow diverted down the tailings lines. This same proportion was used to estimate the annual decant flows during the earlier period (see Figure 13).

6.5 Measured Seepage

Over the life of the tailings impoundment, seepage has been observed at two main locations: downstream of Dam 1 and just east of Dam 4 in the ridge separating the Section 35 and Section 36 arroyos. In 1975, the mine installed an interception system to collect these two seepages and deliver them to the Red River via a network of pipelines. Since that time the interception system has evolved with the addition of extraction wells and new cutoff trenches. Full details of the interception system are presented in the Revised Closure Plan for the tailings impoundment (RGC, 1998).

Figure 15 shows the monthly record of combined flow from these two seepages. Most of these data were obtained from the Discharge Monitoring Reports that Molycorp submits to the EPA as a requirement of their NPDES permit (No. NM0022306). For the period prior to 1983, measurements for these seepages were obtained from tailings impoundment inspection reports and from water quality data sheets located in the Molycorp filing system. Owing to the nature of seepage flows, missing data were patched using linear interpolation.

Old inspection reports indicate that a measurable amount of seepage once emanated from the west abutment of Dam 4. In about 1977, the seepage rate apparently peaked at 300 gpm. A year later the seepage rate had reduced to 5 gpm and by 1986 to zero.

6.6 Evaporation

Evaporation estimates were required for all 5 subbasins incorporated into the water balance analysis. For three of these subbasins (Nos. 1, 3 and 5), an assessment was only required of the evaporation rate from land surfaces (i.e., evapotranspiration). For the remaining two subbasins, consideration also had to be given to the more prolific rate of evaporation that occurs from ponds and wetted tailings beaches.

6.6.1 Pond and Beach Evaporation

Ponds and wetted beaches were assumed to evaporate at the same rate. Accordingly, they were lumped together and designated the "wetted area". This wetted area was further assumed to evaporate at the equivalent rate as a large lake. Based on these two assumptions, the evaporation flux was taken to equal the product of wetted surface area and the lake evaporation rate (46.5 inches per year).

Many observations have been made over the years of the extent of the wetted surface areas within the tailings impoundment. These were obtained from aerial photographs and field surveys. The observations did not span the full period of interest and, accordingly, an estimation technique was required to infill missing data. The following information was assembled to implement the technique:

- a reconstructed record showing how the footprint of the tailings deposit varied with time (in order to place an upper limit on the size of the wetted area);
- record of observed wetted surface areas (pond plus wetted beach);
- an early (1979) measurement of total pond area (but not wetted beach area); and,
- an annual record of the water delivered to the tailings impoundment via the tailings lines.

The basic premise of the estimation technique was that the wetted surface area would be correlated with the amount of water discharged from the tailings lines. In other words, the larger the inflow rate, the larger the wetted surface area. Figure 16 illustrates the mechanics of the technique. The top plot graphically presents the first three items listed above while the bottom plot presents the annual discharge record for the tailings lines. A dashed line is superimposed on the top plot to show how the wetted surface area was interpreted to vary over the life of the tailings impoundment. This line was forced to pass through observed data and then to follow, more or less, the pattern of the tailings slurry discharge record. The total footprint area of the tailings deposit provided a constraint on how large the wetted surface area could actually be.

In examining Figure 16, it should be noted that, for the most part, the observed values of wetted surface area are not spot measurements. Rather, they are weighted annual averages of monthly values. To obtain the annual values, the monthly observations were first weighted according to a typical seasonal evaporation pattern (see Figure 8) and then averaged. This was done in recognition that:

- the wetted surface area fluctuated during the year in sympathy with variations in the tailings slurry discharge, precipitation and snowmelt; and,
- the size of the wetted area during the summer is of greater importance than the size during the winter for the purpose of assessing the annual evaporation flux.

The above discussion provides the basis on which pond evaporation was estimated for Subbasin 2. For Subbasin 4 (incremental basin of Pope Lake), the analysis was much simpler. In this case, the pond was set equal to 3 acres during periods when water was being decanted from the tailings impoundment into Pope Lake. Otherwise, the pond was assumed to be completely dry. The value of 3 acres was reported in early inspection reports of the tailings impoundment.

6.6.2 Evapotranspiration

The tailings impoundment is located in an area where mean annual evapotranspiration is practically identical to mean annual precipitation. With this observation, the annual record of evapotranspiration was estimated using the following climatic water balance:

$$ET = P - R - \Delta S$$

where: ET = estimated annual rate of evapotranspiration;

P = observed annual precipitation at Cerro;

R = estimated annual yield (combined overland flow and groundwater flow); and,

ΔS = change in storage of soil moisture from beginning of year to end of year.

For the purpose of the water balance analysis, the subbasins were assumed to generate a constant yield equal to the estimated long-term runoff estimated in Section 5.3 (0.4 inches per year). Accordingly, the change in storage was set to zero and the annual record of evapotranspiration was estimated by subtracting 0.4 inches from each annual precipitation value in the Cerro climate record.

The above analysis provided a record of annual evapotranspiration rates. These were converted to annual fluxes by multiplying them by an appropriate area. For Subbasins 1, 3 and 5, this area was the total drainage area. For the other two subbasins, the value used was obtained by subtracting the wetted surface area from the drainage area. In this way, double accounting of evaporation losses was avoided.

6.7 Precipitation

The climate record for the Town of Cerro was used to assess the annual precipitation that fell over the entire tailings impoundment basin during the period 1960 to 1999. Precipitation fluxes for the individual subbasins were obtained by multiplying the Cerro measurements by the measured drainage areas.

6.8 Irrigation

Irrigation ditches cross Subbasins 1, 3 and 5. These ditches, known as acequias, are unlined and undoubtedly contribute flow to the underlying aquifers. No estimates were made of this contribution. Historical records of flows conveyed by the individual ditches appear not to be available. Without such data, the estimation of the ditch leakage would be most difficult. Losses from these ditches likely contribute a portion of the observed discharges of the cold and warm springs located along the northern bank of the Red River between the Highway 3 bridge and a point just downstream of the fish hatchery.

6.9 Change in Storage

The water balance kept track of two storage elements within the tailings impoundment: ponds and tailings voids. Different methods were required to assess the changes in the volume of water stored within these two elements.

6.9.1 Ponds

No systematic records were maintained of the total volume of water contained in the ponds overlying the deposited tailings. Despite this, it was possible to approximate the pond volume using a surrogate variable, the total wetted surface area. Section 6.6.2 provides a discussion of how the history of wetted surface area within the tailings impoundment was reconstructed.

Wetted surface area was converted into an equivalent pond volume using the following plausible assumptions:

- the pond surface at any given time was equal to two thirds of the wetted surface area; and,
- the average depth of the ponds was one metre (3.3 ft).

The first assumption was based on a few observations made by mine personnel in which the component parts of the wetted area (viz., pond surface and wetted beach) were recorded separately, and not as a combined number. No information was located to test the accuracy of the second assumption.

6.9.2 Tailings Voids

The average porosity of the tailings deposit is estimated to be about 43%. For many tailings impoundments, knowledge of this parameter is all that is required to quantify the volume of water stored in the tailings voids. However, this is not the case for the Molycorp tailings impoundment. This deposit is under drained by the permeable alluvial foundation soils and has been partially dewatered over time under gravity forces. Accordingly, the voids can not be assumed to be 100% saturated. An allowance must be made for the air content of the voids.

Section 4.0 above outlines the procedure used to assess how the void space in the tailings deposit increased over the period 1966 to 1999. The remainder of this subsection describes how this void space was partitioned into its air and water phases.

The assessment of air content in Section 36 relied heavily on a seepage study prepared by one of Molycorp's geotechnical consultants (Geocon, 1983). One of the objectives of the Geocon study was to estimate the seepage rate from the Section 36 impoundment. Although the Geocon study did not provide an explicit estimate of the air content of the tailings deposit, it did provide an adequate basis from which to make such an estimate.

Two separate analyses were performed using information extracted from the Geocon study. The purpose of the first analysis was to make a point estimate of the air content in the tailings deposit. This entailed defining the water table in the tailings deposit for a specific date. The location of the water table was used, in turn, to determine the approximate volume of unsaturated tailings in the deposit. Using an average water content for unsaturated tailings, an estimate was then derived of the deposit's overall air content. The Geocon study provided two key pieces of information for conducting this analysis: i) a longitudinal section showing the phreatic surface in the impoundment for January 1982; and, ii) field determinations of the average water content of the tailings located above the phreatic surface (i.e., the unsaturated zone). With these data, the total void space of the tailings deposit was determined to be filled with approximately 89% water and 11% air in the year 1982.

The first analysis provided a "snap shot" of the air and water contents of the Section 36 tailings deposit. An additional analysis was required to assess how these contents varied over the life of the tailings impoundment from 1966 to present. This was done using different techniques for the periods preceding and following the year 1982. For the period up to 1982, the mine experienced no major shutdowns and tailings slurry was delivered to the Section 36 impoundment on a nearly continuos basis. Based on this, the air content was assumed to linearly increase from zero to the 11% value over the period 1966 to 1982. In the subsequent period, the delivery of water to

Section 36 was intermittent owing to the temporary mine shutdowns and the development of the new storage area in Section 35 behind Dam 5A. Due to the fluctuating water supply, a different approach was required to estimate variations in air content. The adopted approach involved performing a localized water balance for the tailings voids. During periods of little or no flow to Section 36, the tailings were assumed to gradually drain, thus increasing the size of the unsaturated zone. In contrast, the size of the unsaturated zone was assumed to remain stagnant during periods when tailings were being delivered to Section 36. To apply the localized water balance, an estimate was required of the net drainage rate during periods of shutdown. This net drainage rate was estimated by Geocon to be 0.0036 $ft^3/day/ft^2$, based on the following observations:

- drainage of the tailings by lowering of the phreatic table involved a reduction in the average moisture content from about 30 to 15%; and,
- the average rate of decline in the phreatic surface in the vicinity of Dam 1C was about 5.4 feet per year (during a mine shutdown in the early 1980's).

The results of applying the above analyses to the Section 36 deposit are displayed on the top plot of Figure 5. A similar set of analyses as outlined above was also prepared for the Section 35 deposit. The results for this second deposit are shown on the bottom plot.

6.10 Infiltration to Groundwater

This is a component of the water balances of all five subbasins. A range of different techniques were adopted to assess its magnitude, depending on which subbasin was being examined.

For Subbasins 1, 3 and 5, the infiltration rate was set equal to the estimated average yield of the area. The tailings impoundment is in a semiarid region with low runoff. The analysis described in Section 5.3 estimated the long-term annual yield of this area to be 0.4 inches, as expressed in the same units used for precipitation and evaporation. This amounts to 3% of the mean annual precipitation. Over the period 1960 to 1999, the entire yield was assumed to infiltrate the ground surface and recharge the underlying groundwater aquifers. No allowance was made for a surface component of the yield. This assumption appears reasonable based of the already mentioned behaviour of the diversion channels constructed on the west and east sides of the impoundment (i.e., there is no evidence or observations that these channels have ever carried flow, with the exception of flows originating from irrigation ditches). No allowance was made for fluctuations in the infiltration rate over the period 1960 to 1999. The fluctuations are likely small because moisture storage in the soil and rock would tend to attenuate the infiltration rate. In any event, no significant inaccuracies in the overall water balance are caused by assuming a constant infiltration rate because this flux is small relative to other components of the water balance.

For Subbasin 2 (the tailings impoundment area), different estimation techniques had to be employed for different periods. For the period preceding tailings deposition (i.e., prior to 1966), the infiltration rate was estimated using the same method as outlined above. From 1966 to 1969, or the period when excess water from the tailings impoundment was decanted through decant conduits under Dam 1, the infiltration rate was estimated using Darcy's Law (Q=KiA). The tailings pond was assumed to lie entirely over the tailings deposit so that all seepage would have to pass through the tailings deposit. The hydraulic gradient (i) was assumed to be oriented in the vertical direction and have a value of 1.0 (i.e., free draining). A vertical hydraulic conductivity (K) of 6.3 x 10^{-6} cm/s was selected (based on an estimate made by Geocon in their 1983 investigation of the tailings deposit characteristics). Finally, the cross-sectional area available for flow (A) was set equal to the estimated footprint of the tailings deposit for the particular year.

The rest of the infiltration record for Subbasin 2, from 1970 to present, was assessed using the continuity equation (i.e., inflows – outflows = change in storage). In essence, groundwater infiltration was set equal to that portion of the tailings impoundment inflows that was not evaporated, decanted, discharged to Outfall 002, stored in the voids of the tailings, or stored in the tailings ponds. Two important points should be noted about the reconstructed record of groundwater infiltration for the period 1970 to present:

- its estimated annual values contain the accumulated errors in all of the other water balance components; and,
- for the period prior to 1975, the estimated annual values implicitly include the seepage that would have emerged at the toe of Dam 1 and along the ridge separating the Section 35 and Section 36 arroyos (i.e., the seepages that now comprise the flow at Outfall 002). This is because the measured flow record for Outfall 002 only starts in 1975.

Infiltration from Subbasin 2 has either of two fates. It can recharge the shallow alluvial aquifer system or a deep aquifer system in deep alluvium/volcanics (c. section 3). A method was required to partition the total infiltration between these two aquifers. This was done in a very approximate way using the following observations about the tailings impoundment and its underlying geology:

- infiltration from the Dam 1 arroyo primarily recharges the shallow aquifer while infiltration from the Dam 4 arroyo recharges the deep aquifer (based on results presented in RGC's 1997 modelling study of the groundwater system in the vicinity of the tailings impoundment);
- the surficial deposits in the tailings impoundment area generally have a greater permeability than the deposited tailings; and,
- the greatest opportunity for tailings water to come in direct contact with the surficial deposits is in the Dam 4 arroyo. This arises for two reasons. Firstly, the vast majority of the decant channel network lies within this arroyo. Secondly, the process pond behind Dam 5A lies over both deposited tailings and natural ground. The ponds in the Dam 1 arroyo have tended to be formed exclusively over deposited tailings.

Based on these points, the deduction was made that the greater proportion of the infiltration from Subbasin 2 would recharge the deep aquifer. Furthermore, infiltration to the shallow aquifer probably originates primarily from the tailings deposited in the Dam 1 arroyo. An estimate of seepage from the Dam 1 tailings was based on the 1983 Geocon seepage study that was referenced above in the section on tailings void storage. The unit tailings dewatering rate of 0.0036 $ft^3/day/ft^2$ was used to estimate the amount of infiltration from Subbasin 2 to the shallow aquifer. The amount of infiltration to the deep aquifer was then calculated as the difference between the total groundwater infiltration and the amount estimated to recharge the shallow aquifer.

To assess the magnitude of groundwater infiltration from Subbasin 4 (incremental basin of Pope Lake), a combination of estimation techniques was employed. Darcy's Law was used to approximate losses from the bottom of Pope Lake for periods when this reservoir actually contained water. The hydraulic conductivity of the base of this reservoir was assumed to be 3 x 10^{-5} cm/s (based on the vertical hydraulic conductivity of mixed alluvium used in RGC's 1997 investigation of the tailings impoundment groundwater conditions). The hydraulic gradient was assumed to be oriented vertically downward and possess a value of 1.0. Pope Lake has a surface area of about 3 acres when full. This area was used to approximate the flow cross-sectional area for application of Darcy's Law.

The area of the subbasin beyond Pope Lake was assumed to infiltrate at a rate of 0.4 inches per year, or the same rate adopted for Subbasins 1,3 and 5.

6.11 Groundwater Flows

The results of hydrogeological studies summarized in section 3 were used to formulate the conceptual representation of the groundwater system adopted for this water balance analysis (see second flowsheet of Figure 12). Specifically, the following three flowlines shown on Figure 12 were derived from the existing groundwater model: (i) the groundwater inflow to the shallow aquifer from water originating outside of the study area (referred to in the groundwater study as "underflow in shallow aquifer"); (ii) the groundwater inflow to the deep aquifer from outside sources ("underflow tin deep aquifer"); and, (iii) the percolation from the shallow into the deep aquifer system.

6.12 Results of Water Balance Analysis

The water balance for the tailings impoundment and adjoining areas was reconstructed for the 40-year period from 1960 to 1999. This period was selected to encompass the full life of the tailings impoundment and to also include a short period that pre-dated the development of the facility. A considerable amount of data had to be assembled and processed in order to prepare the water balance. To facilitate working with this large database, the water balance was prepared on a spreadsheet. The output from the spreadsheet uses an annual time step. However, much of the input data were entered into the spreadsheet at much finer time increments (monthly, weekly and even daily). This was done to improve the accuracy of computed annual flow rates, particularly for water balance components that experienced large fluctuations over short periods (e.g., decant flows).

The results of the water balance analysis are summarized using two types of presentations, flowsheets and time graphs. The former type was selected to convey an understanding of how the various water balance components are interconnected and also to show the long-term average flow rates of all the flowlines. The time graphs, on the other hand, were prepared to reveal the year to year variations in flow rates for some of the more important flowlines.

The flowsheets were prepared for three periods: i) 1966 to 1999; ii) 1976 to 1985; and, iii) 1992 to 1996. The flowsheets for these periods are presented in Figures 12, 17 and 18, respectively. The first figure encompasses the full life of the tailings impoundment from the commissioning date to the present. The second figure covers a 10-year period in which Molycorp conducted an intensive water quality monitoring program of the Red River in the vicinity of the tailings impoundment. This observation period also represents a time period of "full production". The third period represents the recent extended "shut-down" period. The latter two periods were selected to illustrate the influence of active tailings discharge on the water and load balance of the tailings facility. The water balance for the shut-down period is the one most relevant to closure as such conditions are likely to be representative of the first 10 or more years post closure.

The general layout of the flowsheets are described above in Section 6.2. The numbers on the flowsheets are in units of ft^3/s and represent the average flow rate for the entire period represented by the flowsheet. It should be noted that the averages include years of zero flow. For example, decant from Pope Lake occurred in 16 years out of 34 years during the period from 1966 to 1999. Accordingly, to compute the average decant rate for the 1966-1999 flowsheet, the annual decant rates for this period were accumulated and divided by 34 years, and not 16.

The water balance includes some storage components (e.g. water stored in voids of tailings). These storages are displayed as bracketed numbers in the boxes used to represent the various components of the water balance. The numbers represent the total change in volume from the beginning to the end of the period of interest. For compatibility with the numbers on the flowlines, these storages are expressed as long-term flow rates in units of ft^3/s (i.e., total change in storage over period divided by the number of seconds in that period). A positive value denotes a net increase in storage while a negative number indicates a depletion.

Figure 19 shows the time graphs. This figure summarizes all of the components of the water balance for the tailings impoundment proper (Subbasin No. 2). As an aid in appreciating the relative magnitudes of the various components, all the graphs use identical scales for their x-axes, which run from 0 to 12 ft^3/s. The top two graphs show the inputs to the tailings impoundment, namely: precipitation and water delivered from the mine site to the tailings impoundment via the tailings lines. The next four graphs show the outflow streams: evaporation, decant, measured seepage, and infiltration to groundwater. The final graph shows the combined annual change in storage within the tailings voids and tailings ponds.

The following observations can be drawn from the flowsheets and time graphs:

- The single largest component of the overall water balance is the flow of groundwater beneath the facility. The study area defined for the groundwater system (see Figure 11) has an estimated total groundwater inflow of about 16.8 ft^3/s. This is water that originated from Cabresto Creek and the western slopes of the Sangre de Cristo Mountains. This flow discharges primarily in the reach of the Red River between the Highway 3 bridge and a point just downstream of the fish hatchery.

- The next largest inflow to the system is the liquid fraction of the tailings slurry. Over the period 1966 to 1999, it has had an average flow rate of 5.8 ft^3/s.

- The single largest outflow component from Subbasin 2 is infiltration to the underlying groundwater system (excluding the intercepted seepage monitored at Outfall 002). Over the period 1966 to 1999, the average rate of infiltration was estimated to be 2.9 ft^3/s. However, the rate of infiltration fluctuated widely from year to year in sympathy with the volume of water delivered to the tailings impoundment by the tailings lines.

No allowance has been made in the water balance for the storage of water in the unsaturated alluvial sediments below the tailings impoundment. Boreholes drilled in the impoundment show that these sediments extent to great depth, particularly below the Section 36 arroyo. Given that the pre-mining water table was also at great depth, these sediments have undoubtedly acted to attenuate the seepage flows originating from the tailings impoundment. In this attenuation process, a significant portion of the infiltration from the tailings impoundment would have been stored in the sediments and, accordingly, would not have discharged to the Red River. Examination of this storage and its effects on the seepage rate from the tailings impoundment is beyond the scope of this report. A rigorous assessment of the effect of moisture storage in the underlying alluvium would require the application of a transient unsaturated-saturated flow model.

An "order-of-magnitude" calculation was performed to provide a first approximation of the size of this available moisture storage. The calculation was based on the following information and assumptions:

- area of Subbasin 2 is 2.0 square miles;
- the average depth of soil available for storing seepage below the Section 35 arroyo ranges from 15 ft to 30 ft (assuming the depth of alluvium either tapers to the north or remains similar to the depth of alluvium indicated by the boreholes in the vicinity of Dam 4);
- the average depth of alluvium below the Section 36 arroyo but above the pre-mining water table falls in the range of 50 to 150 ft (based on the geologic logs available for this arroyo and reasonable assumptions regarding the slope of the pre-mining water table as it extended northward from the Red River) ;
- the moisture content of the alluvium was assumed to increase over the life of the facility by 10% (volumetric). This estimate was based on a soil moisture characteristic curve developed for a sample of alluvium material (see Figure 4.3 of RGC, 1997). This curve shows a volumetric moisture content of 18% at 10,000 cm suction and 30% at full saturation.

Based on the first three items, the bulk volume of unsaturated soil below the tailings impoundment falls in the range of 2 to 5 billion cubic feet. Assuming the water content of these soils has increased by 10% from 1966 to present, the volume of water stored would be about 0.2 to 0.5 billion cubic feet. Averaged over the 34-year life of the impoundment, these volumes are equivalent to long-term accumulation rates of about 0.2 ft^3/s and 0.5 ft^3/s, respectively.

In the following section the estimate of infiltration to groundwater derived from the water balance analysis is compared to earlier estimates of seepage from the Questa tailings facility derived by other independent methods.

6.13 Comparison of Seepage Estimates

Figure 20 presents a plot of the estimated rate of annual infiltration for the period 1980-1999 (based on the water balance analysis). During this period two other estimates of tailings seepage were made by other investigators: (i) a seepage estimate by Geocon based on observed water level decline in 1983 and (ii) a seepage estimate by Vail Engineering based on a sulfate load balance in the Red River in 1993. Their estimates of tailings seepage are shown in Figure 20 as horizontal lines or comparison.

In 1983, Geocon studied the seepage losses from the southern portion of section 36 tailings area. First, all piezometer monitoring data collected from 1981 to 1983 were reviewed to estimate the rate of lowering of the phreatic surface within the tailings. Due to construction in 1982-83 and shut-down of the mill since August 1981, there had been practically no discharge of tailings slurry into this area until the start-up of the mill in October 1983. Hence, the decline in the phreatic surface during this period could be interpreted as the rate of seepage through the tailings (Geocon, 1983). Second, Geocon (1983) carried out a parametric modeling study by using finite element seepage analyses covering a wide range of assumed horizontal and vertical permeability values. Based on this analysis Geocon computed the outflow rate through the base of the tailings as $3.0 \cdot 10^{-3}$ $ft^3/day/ft^2$ which is equivalent to $1.5 \cdot 10^{-3}$ cfs per acre. Assuming similar drainage conditions for the entire foot print area of the Questa tailings facility (640 acres) the total seepage rate would be about 1 cfs.

The Geocon estimate of 1 cfs matches the estimated infiltration rate for the period of analysis, i.e. averaged over the period 1981-83, fairly well (Figure 20). However, infiltration rates estimated with the water balance method for years of full production are significantly higher than 1 cfs (see for example period 1989-1991) (Figure 20). Two factors may account for the significantly higher seepage rates estimated for the years of "full production" relative to the Geocon estimates (obtained from a shut-down period). First, the tailings process water may infiltrate very quickly through very permeable beach material during periods of active discharge. This process water may then discharge laterally through permeable embankments and/or permeable natural alluvial ridges. In other words this rapid infiltration water may not mix with old process water by way of infiltrating down to the phreatic surface and draining at a more steady rate through the base of the tailings mass.

However, the above hypothesis is not consistent with observed seepage rates collected in the seepage interception system downstream of Dam 1 and to the east of Dam 4 (i.e. in seepage barriers 002 and 003). For example, during the period 1982-1988 measured seepage rates collected in the seepage interception system ranged only from about 0.6-0.9 cfs (i.e. by 30% of the maximum, Figure 15). In contrast, the annual infiltration rates estimated over the same time period with the water balance method ranged by several hundred percent (Figure 20). Clearly, the observed fluctuations in seepage are much smaller than those estimated with the water balance method.

While rapid percolation through permeable beach areas appears unlikely for the tailings overlying alluvial soils (i.e. Section 36 and easterly portions of Section 35) this mechanism may be a factor in areas where permeable tailings directly overly very permeable volcanic rocks (i.e. westerly portions of Dam 4 and Dam 5 impoundments). Due to the very permeable volcanics the base of the tailings in this area is free-draining resulting in unity gradients within the tailings mass (RGC, 1997). Under those conditions the infiltration rate would be equal to the saturated hydraulic conductivity of the tailings. In areas with predominantly coarse tailings (e.g. near Dam 4) the infiltration rate could be significantly higher than the average infiltration rate of $3.0 \cdot 10^{-3}$ ft/day ($1.1 \cdot 10^{-6}$ cm/s) estimated by Geocon for the Dam 1/1C area.

Secondly, the Geocon analysis does not include seepage losses as water was conveyed along the system of decant channels or while being stored in the process water pond behind Dam 5A. Seepage losses from these areas could be substantial as the underlying formation (volcanic rocks) are reportedly very permeable (RGC, 1997). The exact seepage losses are difficult to estimate as they are controlled by the foot print area and the degree of sealing of the permeable rocks by tailings. However, it is reasonable to assume that these seepage losses are highest during periods of "full production" and lowest during shut-down periods.

If present, such short-term fluctuations in infiltration rates to the deep volcanic aquifer would be significantly attenuated due to storage effects in the very deep unsaturated zone (see section 6.12) and the large degree of dilution and dispersion in the receiving aquifer (see section 3.0). In other words they may not necessarily result in significant fluctuations in the contaminant concentrations in the deep aquifer. A more detailed discussion of contaminant loading to the deep aquifer (based on predicted and observed sulfate concentrations) is provided in section 7.2.2.

A second independent estimate of seepage from the Questa tailings facility was obtained by Vail Engineering. In April 1993, Vail conducted a water quality survey along the Red River between the State Road 3 bridge and the Red River fish hatchery (Vail, 1993). Using a serious of mass balance calculations the total seepage from the impoundment was estimated to be about 2.3 ft^3/s (Vail, 1993). The mass balance calculations assume that (i) sulfate is conservative, (ii) the flows and concentrations of the various mass balance components are at steady-state, and (ii) all seepage from the Questa tailings facility discharges into the Red River reach between Questa and the Red River fish hatchery. To be directly comparable to the estimated infiltration record, the measured flow at Outfall 002 (0.6 ft^3/s) had to be subtracted from Vail's estimate. This suggested that the unmeasured seepage from the impoundment in 1993 was about 1.7 ft^3/s (Figure 20).

Note that Vail's estimate of seepage is based to a large degree on sulfate concentrations in spring flows discharging from the shallow alluvial aquifer and deep volcanic aquifer (i.e. cold springs and warm springs, respectively). Any short-term fluctuations in tailings seepage would be averaged out in these spring flows resulting in fairly constant water quality in these springs (see section 7.1.4). Hence the seepage estimate by Vail is representative of a longer-time average in the order of several years, i.e. the average travel time in the respective aquifers. The average seepage estimate for the last 3 and 5 years prior to the Vail study (1993) obtained with the water balance method were 1.56 and 2.67 cfs, respectively. Clearly, the shorter-term average compares very well with the Vail estimate whereas the 5 year average is significantly higher than the Vail estimate.

This comparison demonstrates that caution has to be used when comparing the annual infiltration rates computed from the tailings water balance with water quality observed in the receiving environment. As mentioned earlier no allowance was made in the water balance for the storage of water (and associated contaminants) in the vadose zone and/or transport time in the receiving groundwater aquifers below the tailings impoundment and up to the respective monitoring point (well or spring discharge point) (see also section 7).

The uncertainty in the amount of tailings seepage was addressed during development of the local groundwater flow model (RGC, 1997). The tailings seepage rate was varied from 1 to 3 cfs in a sensitivity analysis. The results of the sensitivity analysis indicated that these variations in tailings seepage would have no significant effect on the local groundwater flow system (in terms of flow direction and water table mounding) other than a proportionate increase in the groundwater flow rates. The long-term average seepage rate for the Questa tailings facility estimated with the water balance method (i.e. 2.7 cfs) falls within the range of seepage rates assumed for the sensitivitty analysis. In other words these higher seepage rates, if correct, are not expected to result in significant changes to the water table elevations and/or groundwater flow paths determined with the local groundwater flow model.

7 CHEMICAL LOAD ANALYSIS

Chemical load balances has been calculated for the following chemical constituents:

- Sulfate (SO_4);
- Fluoride (F);
- Molybdenum (Mo); and
- Manganese (Mn).

These four constituents have been selected for analysis because they are elevated in seepage from the Questa tailings impoundment in that they may exceed numerical New Mexico Groundwater Standards (NMGWS).

7.1 Water Quality Data Review

All available water quality monitoring data for the Questa tailings facility were reviewed in order to develop the load balances. Water quality data were available from four different sources:

- Historic outfall data (period 1975 - 1985) consisting of weekly water quality monitoring data (spot measurements) for decant (outfall 001), seepage barrier 002 and seepage barrier 003 (Molycorp files);
- Recent outfall data (period 1988 - 1999) consisting of monthly water quality monitoring data (monthly average and min/max data) for outfall 002 (EPA files);
- Monitoring well data (period 1993 - 2000) consisting of annual to quarterly water quality monitoring data from all monitoring wells under DP-933 (Molycorp files). and
- Spring survey data (period 1993 - 2000) consisting of annual to quarterly water quality monitoring data from selected springs at the lower Red River under DP-933 (Molycorp files).

7.1.1 Historic Outfall Data

Figures 21a-e show the historic concentrations of pH, sulfate, fluoride, molybdenum and manganese in outfall 001 and seepage barriers 002 and 003 for the period 1975-1985. The data record for outfall 001 is only plotted until the end of 1982, i.e. for the period when untreated decant water, i.e. the supernatant water remaining after settling out of the tailings solids in the tailings pond, was discharged. In 1983, the IX treatment plant was commissioned and subsequently, all decant water was treated prior to discharge into outfall 001 (resulting water quality not shown here). Table 3 provides summary statistics for the concentrations of sulfate, fluoride, molybdenum and manganese for the various outfalls.

This historic outfall data provide insights into the quality of water leaving the tailings facility as surface runoff (outfall 001) and subsurface seepage (seepage barriers 002 and 003). By inference, the outfall 001 data may also provide clues about the quality of the water entering the facility as process water (assuming evpotranspiration is negligible) and potential sources/sinks for the various constituents within the tailings (by way of comparing outfall 001 data with seepage barrier data).

The water quality of the decant water (outfall 001) shows a modest increase over time in all four constituents likely due to changes in the mineralogy of the ore milled throughout this period and/or changes in the milling process. Superimposed on this trend are significant short-term variations in water quality (Figure 21a-e). The short-term variations do not appear to correlate with the seasons nor are they consistent among the four constituents suggesting that climatic factors (e.g. evapotranspiration, snowmelt) did not have a strong effect on the decant water quality (i.e. no apparent concentration or dilution of the tailings pond water) during this observation period. In other words the data suggest that the water quality of the decant water is representative of that of the process water discharged into the tailings facility. Unfortunately, no water quality data are available on the process water (as delivered to the tailings facility) for this period to check this preliminary conclusion.

The location of the seepage barriers 002 and 003 are shown in Figure 2b. Based on their location the majority of seepage intercepted in 002 likely originates from Section 36 (behind Dam 1/1C) whereas the majority of seepage intercepted in 003 likely originates from Section 35 (behind Dam 4). The water quality of the tailings seepage intercepted in these two seepage barriers differed significantly from one another. The seepage collected in seepage barrier 002 showed lower sulfate concentrations (~700-800 mg/l) than seepage collected in barrier 003 (900-1100 mg/l). In contrast, all other constituents (F, Mo and Mn) were substantially lower in seepage collected in seepage barrier 003 compared to those observed in barrier 001. The data illustrate the variability in seepage water quality that may be discharging from the same tailings facility. Potential factors that may contribute to the observed differences in seepage water quality include (i) the amount of old process water versus newly infiltrated precipitation water contributing to seepage; (ii) geochemical reactions occurring either within the tailings or within the alluvial soils; and (iii) the degree of mixing with local groundwater intercepted in the seepage barrier. Based on the existing data it is hypothesized that natural attenuation in the alluvial material is responsible for the much lower concentrations of the reactive constituents fluoride, molybdenum and manganese in seepage barrier 003 compared to seepage barrier 002 (c. section 7.1.3).

Figure 22 shows scatter plots of F, Mo, Mn versus sulfate for the three observation points. Both Mo and F show an inverse relationship with sulfate (R^2=0.28) in seepage collected in the Dam 1 arroyo (outfall 002). This inverse relationship may be a result of varying contributions of process water to tailings seepage. The high molybdenum concentrations may be indicative of a greater proportion of remnant process water (typically high in pH, F and dissolved Mo) stored in the finer-grained tailings mass and contributing more to overall seepage flows during low flow periods. In contrast, the high sulfate concentrations could be a result of fresh recharge water percolating through more permeable beach zones and washing out oxidation products (in particular calcium and sulfate) during high flow periods.

7.1.2 Recent Outfall Data

Figures 23a-d show the recent concentrations of sulfate, fluoride, molybdenum and manganese in outfall 002 for the period 1988-1999. Outfall 002 represents seepage collected in all seepage barriers (including 002 and 003) and groundwater extracted from several extraction wells (starting at the end of 1997). All concentrations shown are total concentrations determined on unfiltered samples (as required under the NPDES permit). Summary statistics for the various constituents in outfall 002 are shown in Table 3. Note that sulfate is not regulated under the NPDES permit and therefore is not included in this data base.

The recent water quality measured in outfall 002 is generally very similar to the historic water quality in seepage barrier 002 (which provides the majority of intercepted seepage) (Table 3). The water quality of the intercepted seepage shows some fluctuation in time (Figure 23a-c). However, these fluctuations appear to be more related to water management (e.g. temporary shut-down in 1992, expansion of the seepage interception system) than natural factors such as spring runoff. For example, the start-up of the extraction well system at the end of 1997 shows a clear decrease in all constituents (see e.g. sharp decline in molybdenum in fall/winter 1997, Figure 23c). The overall consistency in the various contaminant concentrations in tailings seepage over the last 25 years (from 1975 to 2000) strongly suggests that the tailings are at a geochemical equilibrium (steady-state). This monitoring data is supported by geochemical testing of the tailings solids which did not indicate any signs of strong oxidation and/or acid generation in the tailings (RGC Report 052004/1).

7.1.3 Groundwater Monitoring Data

Figure 24 shows the location of the various monitoring wells downstream of the Questa tailings facility. The only monitoring well located upstream of the tailings facility is the Change House Well (MW-CH) immediately to the west of the Section 36 impoundment (next to the administration building, not shown in Figure 24).

Figures 25a-b show time trends of sulfate, fluoride, pH, molybdenum and manganese for the period 1993 to 1999 in those extraction and monitoring wells located immediately downstream of the Section 36 tailings impoundment. The geodetic groundwater levels are shown for comparison.

The water quality of seepage in the main drainage channel (EW-5A, 5B and MW-C) shows elevated concentrations of all constituents (SO4, F, Mo and Mn). The observed range of these constituents is consistent with the long-term average values for outfall 001 (decant or process water, see Table 3) suggesting that the seepage intercepted is predominantly old process water.

In contrast, water quality of seepage in the western portion of the Dam 1 arroyo (EW-5C and 5D) shows only elevated concentrations for SO4 comparable with process water. The other constituents F, Mo and Mn show much lower concentrations than the process water and all meet numerical groundwater standards (NMGWS). This water quality is consistent with that of the seepage intercepted in the seepage barrier 003 (Table 3). Natural attenuation mechanisms (precipitation and/or adsorption) in the alluvial soils along the flow path may account for this reduction in contaminant concentrations. The higher attenuation rates in the western portion of the arroyo (compared to the main drainage channel) may be related to the significantly lower seepage rates (allowing more equilibration time and less total loading).

Figures 26a-b show water quality time trends in wells located in Dam 1 arroyo at various distances downstream of the Section 36 tailings impoundment. The geodetic groundwater levels are again shown for comparison.

The only wells consistently showing water quality exceedances above numerical groundwater standards (NMGWS) were MW-7A and EW-3 (for SO4 only) and MW-2 (for SO4, Mo and Mn prior to 1997-98). Of those wells only MW-2 is located downstream of the seepage interception system. The water quality in MW-2 has significantly improved in manganese, sulfate and in particular molybdenum. This improvement is likely a result of the expansion of the interception system (in particular start of pumping of the extraction wells).

Figures 27a-b show water quality time trends in wells located to the east of Dam 1 arroyo along the alluvial hill side which forms the natural southeastern embankment of the Section 36 tailings facility. The geodetic groundwater levels are again shown for comparison.

The groundwater quality to the east of the Dam 1 arroyo is generally less impacted by tailings seepage than in the Dam 1 arroyo. MW-3 is the only well located east of Dam 1 arroyo, which exceeded numerical groundwater standards (NMGWS) for one parameter (SO4). All other wells show contaminant concentrations well below the applicable standard.

Figures 28a-b show water quality time trends in wells located in the deep aquifer system downstream of Dam 1 (MW-12 and EW-3 in alluvium) and downstream of Dam 4 (MW-11 and MW-13 in volcanics). The water quality in the deeper alluvium immediately upstream of the Questa tailings facility (MW-CH) is shown for comparison.

The water quality in the deep aquifer system shows very little impact of tailings seepage. Over the entire monitoring period (1993-1999) no exceedance above numerical groundwater standards (NMGWS) has been observed for any parameter. The elevated fluoride concentrations (~1 mg/l) in MW-11 and MW-13 are typical of background in the volcanic aquifer (c. Table 2.5 in RGC Report 052004/1). After 1997 there has been a small increase in sulfate and molybdenum in the deep wells screened in the volcanics. This small increase is likely a result of the start-up of tailings discharge behind Dam 5 and the associated seepage of process water into the volcanics.

7.1.4 Spring Water Quality

Figures 29 a-b show the water quality in the springs in the lower Red River which were sampled first by Vail as part of their seepage study (Vail, 1993) and which have been sampled quarterly since late 1996 as part of DP-933. As discussed by Vail (1993) the cold springs (#17) and warm springs (#18) represent the water supply for the Red River fish hatchery from the shallow alluvial aquifer (~2.0-3.3 cfs) and deep volcanic aquifer (about 10.2 to 10.5 cfs), respectively. The other stations shown in Figures 29a-b represent two smaller springs in the shallow alluvium (seeps #9 and #10) and deep volcanic (seeps #12 #14), respectively.

The water quality in all springs consistently meets New Mexico Groundwater Standards. For the most part, the water quality in the springs also shows very little variation over the years. The only exception is seep #9 and to a lesser extent #10 (both near Questa springs) which show a clear seasonal pattern in sulfate which is likely a result of dilution due to irrigation water being supplied to the fields upstream of these monitoring stations during the summer months. The overall consistency in water quality in the seeps strongly suggests that any short-term fluctuations in seepage losses from the tailings impoundment (as suggested by the water balance analysis) are being attenuated along the flow path due to storage requirements and/or dilution/dispersion.

The very low concentrations of the reactive constituents (F, Mo and Mn) relative to sulfate in seeps #9 and #10 suggest that molybdenum, manganese and to a lesser degree fluoride are being effectively attenuated by chemical reactions in the alluvial soils. It is likely that similar chemical attenuation mechanisms are also at play in the volcanics. However, this hypothesis is difficult to ascertain from the monitoring data due to the high degree of dilution of tailings seepage (by a factor of 8-12 times based on sulfate) and the high natural background in the volcanic aquifer for some of these reactive constituents (e.g. about 1 mg/l for fluoride).

7.2 Load Balance

7.2.1 Approach

A review of all available water quality data suggests significant physical and chemical attenuation of the four constituents discharged with the tailings seepage (sulfate, fluoride, molybdenum and manganese) in the receiving environment (shallow and deep aquifer system). The physical attenuation (storage, dispersion and dilution) is evidenced by relatively constant sulfate concentrations in the receiving groundwater at significantly lower concentrations than observed at the source. The chemical attenuation is evidenced by significantly reduced concentrations of the reactive constituents (F, Mo and Mn) relative to the non-reactive constituent sulfate.

In order to minimize the influence of physical attenuation on the mass loading calculations all load balance calculations were performed for the entire period of record (1966-1999). This way short-term fluctuations in the estimated infiltration rate (based on the water balance method) were averaged out. The observed consistency in the water quality of the aquifers located downstream of the Questa tailings facility (in monitoring wells and springs) supported this approach.

Briefly, the following approach was taken to developing the load balances for the various constituents.

1. Establish water balance for period 1966-1999 (from water balance analysis);
2. Determine input concentrations for various sources;
3. Determine sulfate load balance; this step included estimating groundwater flow rates required to achieve observed sulfate concentrations in shallow and deep aquifer systems (assuming complete mixing);
4. Determine load balances for reactive constituents; this step included estimating sinks (i.e. chemical attenuation) required to achieve observed F, Mo and Mn concentrations in shallow and deep aquifer systems (assuming complete mixing);

Figure 30 shows the average annual water balance which was modified from the detailed water balance developed for the Questa tailings facility (Figure 12a-b) for the purpose of load balance calculations. This modified water balance has four surface inputs, which differ with respect to their source concentrations:

- Seepage losses of process water;
- Net precipitation on areas beyond tailings deposit;
- Old process water stored in tailings deposit; and
- Tailings pore water originating from precipitation.

Based on the water balance analysis for the Questa tailings facility the long-term average annual infiltration rate was set equal to 3.3 cfs. The majority of this flow (2.3 cfs) was assumed to represent seepage losses, i.e. process water, which is lost directly to the permeable volcanics from decant channels and process water ponds. The seepage from the base of the tailings deposits was assumed to be 1 cfs. The fraction of "old" process water contributing to seepage at the base of the tailings impoundments was estimated to be about 90% with the remaining 10% representing precipitation water that percolates through the unsaturated tailings. The 10% fraction (0.1 cfs) amounts to an average infiltration rate in the order of about 1.4 inches per year (or 10% of MAP) distributed over the entire tailings area. The distinction between "old" process water and "fresh" recharge water is made to account for the significant differences with respect to contaminant loading for these two sources of water (see section 7.2.2 below).

For the purposes of loading calculations an idealized "vadose zone" was introduced into the water balance flow sheet to allow for chemical attenuation prior to interception in the seepage interception system and/or flow into the receiving aquifers. While it is recognized that some of the chemical attenuation likely occurs in the saturated zone (i.e. within the aquifer system) no attempt was been made to distinguish between those two processes.

The groundwater flows into the shallow and deep aquifers were taken from the respective estimates of groundwater flow obtained with the local groundwater flow model (RGC, 1997). The shallow aquifer was further subdivided into an upper "mixing zone" to account for the limited degree of mixing of the tailings seepage with the groundwater flowing in the shallow alluvial aquifer (see Wels et al., 2000 and RGC, 1998 for details). The amount of shallow groundwater available for mixing with the tailings seepage up to the Molycorp property boundary was estimated by matching the observed sulfate concentrations (see section 7.2.2). No such distinct mixing zone could be observed in the deep volcanic aquifer. Hence the entire groundwater flow in the deep volcanic aquifer (within the model domain outlined in Figure 11) was assumed available for dilution and dispersion.

The rate of percolation from the shallow aquifer to the deep volcanic aquifer was also taken from the calibrated groundwater flow model developed by RGC (1997).

7.2.2 *Sulfate Load Balance*

The background and source concentrations used for input into the sulfate load balance are shown in Table 4. The sulfate concentrations in the tailings pond showed significant variations, in particular an increase during the drier summer months suggesting an evaporative trend. The (lower) median concentration was judged to be more representative for seepage losses of process water at surface (along decant channel etc.) whereas the (higher) average concentration was judged to be more representative of process water deposited as pore water with the tailings. The input concentrations for precipitation water infiltrating unsaturated tailings material was estimated from leach extraction tests performed on Questa tailings samples (see RGC 1998 for details). Note that this component of the load balance represents the highest source concentration due to the release of oxidation products from unsaturated tailings.

Figure 31 shows the estimated average annual sulfate load balance for the Questa tailings facility. The annual sulfate load for each pathway is shown in tonnes per year. The values in brackets indicate the calculated sulfate concentration for the particular flow path (assuming complete mixing). Sulfate is assumed to be non-reactive for the concentration ranges observed at the Questa tailings. Hence no sources or sinks are allowed for in this load balance.

Table 5 shows the target concentrations for sulfate in the shallow and deep aquifer systems at the Molycorp boundary and at the respective groundwater discharge points near the Red River. Note that the "cold" and "warm" springs (collected separately as water supply for the Red River fish hatchery) are considered representative of shallow and deep groundwater, respectively, due to their large respective flow rates.

The amount of shallow groundwater flow required to obtain the target sulfate concentration at the Molycorp boundary was about 0.26 cfs (Figure 30). This flow rate represents only about 4% of the total shallow groundwater flow. In other words the tailings seepage in the shallow alluvial aquifer (i.e. Dam 1 arroyo) shows only very limited mixing and dispersion in the underlying aquifer within this limited distance from the source. This conclusion is consistent with previous seepage modeling results which suggested that tailings seepage from Dam 1 remains perched above the local water table for some distance downstream of the toe of the Dam 1 (Wels et al. 2000).

According to the load balance model the sulfate concentrations for shallow groundwater discharging to the Red River would be about 91 mg/l (assuming complete mixing) (Figure 31). This value compares fairly well with the observed sulfate concentrations in the cold springs (83 mg/l, Table 5).

In contrast, the sulfate concentration predicted with the load balance model for the deep volcanic aquifer was significantly higher than the observed target concentrations, both at the Molycorp boundary and in particular at the discharge locations (warm springs) (c. Figure 31 and Table 5). Assuming complete mixing with all assumed groundwater flow in the deep aquifer (16.2 cfs) the calculated sulfate concentration in the deep aquifer system would be about 171 mg/l. This value is fairly close to the target concentration of 147 mg/l at the Molycorp boundary (MW-11 and MW-13). However, the sulfate concentration in the warm springs which represents a large proportion of the total groundwater flow in the deep volcanics is only about 64 mg/l.

Several potential factors could be invoked to explain the discrepancy between the sulfate concentrations predicted by the load balance model and those observed in the deep volcanic aquifer (i.e. warm springs):

1. Infiltration rates estimated with the present water balance analysis (in particular seepage losses of process water) are too high;
2. A higher proportion of tailings seepage recharges the shallow aquifer system (and remains in the shallow aquifer system until it discharges to the Red River);
3. Significant physical attenuation (e.g. storage) occurs in the unsaturated zone above the deep volcanic aquifer;
4. Source concentrations of sulfate are too high:
5. Significant chemical attenuation of sulfate occurs along the flow path; and/or
6. A greater flow of groundwater (than assumed in the load balance) is available for dilution and dispersion of tailings seepage in the deep volcanic aquifer.

Clearly there is some uncertainty in the estimated rate of infiltration, in particular since this component was estimated by inference from all other measured and/or independently estimated components of the water balance. However, all components of the water balance appear relatively closely constraint (estimated to be +/- 10% on a year by year basis). By using the long-term average water balance those uncertainties are expected to average out rather than compound (provided there is no systematic error). The water supply to the tailings facility represents the largest single component and hence the largest potential source for error in the water balance. However, this component is likely also the most accurate due to the detailed records kept by Molycorp on its water usage.

Sensitivity analyses were run using the sulfate load balance model to estimate the annual infiltration required to match the observed sulfate concentrations in the warm springs (i.e. 60 mg/l). Assuming all other water balance components and source concentrations are applicable, the infiltration rate to the deep volcanic aquifer would have to be reduced from 2.7 cfs to 0.56 cfs to obtain the observed low sulfate concentrations. Considering all uncertainties in the water balance analysis such a small infiltration rate to the deep volcanic aquifer appears unlikely.

A second potential factor for the discrepancy in modelled and observed sulfate concentrations in the deep volcanic aquifer is the routing of the infiltration water. The routing of infiltration water to the shallow and deep volcanic aquifer was derived from the groundwater flow model. In addition it was assumed that all seepage losses in excess of 1 cfs infiltrate to the deep volcanic aquifer as seepage losses. Assuming seepage losses to the deep volcanic aquifer amount to only 0.56 cfs and all other seepage is routed to the shallow aquifer system the resulting sulfate concentration in the cold springs would increase to 506 mg/l. This sulfate concentration is significantly higher than what is actually observed in the cold springs (~83 mg/l). In other words re-routing of infiltration water to the shallow aquifer system would provide a better match with observed sulfate concentrations in the warm springs but at the expense of a poorer match with those observed at the cold springs.

Re-routing of seepage waters to the shallow aquifer system would also have no effect on the total loading to the Red River (the ultimate discharge point of both aquifers). According to Vail's analysis the total load of sulfate in the Red River (up to the Red River fish hatchery) could be accounted for by assuming a total seepage rate of 2.3 cfs (Vail, 1993). In other words, a sulfate load associated with approximately 1 cfs of tailings seepage remains unaccounted for in the mass balance for the Red River. Note that Vail's mass balance calculations are directly comparable to our sulfate load balance calculations since concentrations in all springs (including cold and warm springs) remained virtually constant (Figure 29a,b) and very similar source concentrations were assumed in both analyses.

As discussed earlier potential storage of tailings process water in the vadose zone was not included in our water and load balance calculations. Preliminary estimates of storage in the vadose zone range from 0.2 – 0.5 cfs expressed as an average storage rate over the life of the tailings facility (see section 6.12). These estimates indicate that storage of tailings seepage in the vadose zone could account for a significant portion (up to 43%) of the sulfate load that is not accounted for in the load balance for the Red River. However, a more detailed analysis would be required to better define the extent of water and mass load storage in the vadose zone.

Another potential source of uncertainty in the sulfate load balance is the assumed sulfate input concentration for the various sources of water (Table 4). The greatest uncertainty in sulfate concentrations is attached to the flow component termed "tailings pore water originating from precipitation". The sulfate concentration for this flow component was estimated from leach extraction tests performed on Questa tailings (see RGC, 1998 for details). This input concentration (2466 mg/l sulfate) is likely biased towards higher sulfate concentrations since only the "first flush" was examined. Repeated percolation of precipitation water in permeable beach material could result in much lower source concentrations as evidenced in some of the humidity cell testing which indicated an exponential decrease in sulfate concentrations in the leachate over time. The load balance model was used to estimate the sensitivity of this parameter on the sulfate concentration in the deep volcanic aquifer. Assuming the sulfate concentration in pore water originating from precipitation water was only about 550 mg/l (i.e. resulting in an arbitrary seepage concentration at the base of the tailings of about 1000 mg/l), the overall sulfate load to the Red River would only be reduced by 2760-2589 = 171 tonnes/year, i.e. representing a load reduction of only about 1 %. The effect of this load reduction on sulfate concentrations in the deep volcanic aquifer would be quite small (from 171 to 163 mg/l).

While it can not be ruled out, the chemical attenuation of sulfate along the flow path (i.e. in the vadose zone and/or respective aquifer) is considered very unlikely and is not further discussed.

A higher than expected groundwater flow in the deep volcanic aquifer available for dilution and dispersion is another factor that may account for the very low sulfate concentrations observed in the springs emanating from the volcanic springs at greater distance from the Questa tailings facility. Sensitivity runs with the sulfate load model suggest that the groundwater flow in the deep volcanics would have to be as high as 50 cfs to provide sufficient dilution to yield sulfate concentrations that approach those values observed in the warm springs (i.e. 64 mg/l). Much lower flow rates (18.7 cfs) would be required to produce sulfate concentrations of ~120 mg/l, i.e. sulfate values observed in springs discharging from the volcanics in vicinity of the Questa tailings facility (e.g. seep #12 and #14, Figure 29a).

The above sensitivity runs indicate that the groundwater flow required for dilution is quite sensitive to the assumed target concentration. Perhaps the most appropriate target concentration to use would be a flow-weighted average of sulfate from all springs discharging into the Red River between the Questa tailings facility and the Red River fish hatchery. According to Vail (1993) this flow-weighted average sulfate concentration would be about 71 mg/l. A total flow rate of 42 cfs would be required to produce this flow-weighted average sulfate concentration in the deep volcanic aquifer.

The estimated flow rates required for dilution in the deep volcanic aquifer (i.e. 40 - 50 cfs) are close to the total groundwater flow (~50 cfs) estimated by Vail (1988) for the study region. These estimates of deep groundwater flow available for mixing of tailings seepage appear very high and suggest that factors other than higher groundwater flows in the deep aquifer system are contributing to the very low sulfate concentrations observed in the deep aquifer system.

In summary, a number of different factors could contribute to the very low sulfate concentrations observed in the deep volcanic aquifer. The most likely factors include storage of tailings seepage water in the vadose zone beneath the tailings facility, a higher proportion of tailings seepage recharging the shallow aquifer (and discharging to the Red River), and a higher than expected groundwater flow rate in the deep volcanic aquifer providing additional dilution.

Note that no attempt was made during this study to fit the sulfate load model to observed sulfate concentrations at the discharge points (springs) by adjusting the water balance components and/or input concentrations. Such a calibration will be performed as part of the sulfate load model for the entire Red River basin to be submitted in the Report on Conservative Load Model for Red River basin (due on December 15, 2000).

7.2.3 *Fluoride Load Balance*

Figure 32 shows the estimated average annual load balance for fluoride. The annual fluoride load for each pathway is shown in kilograms per year. The values in brackets indicate the calculated fluoride concentration for the particular flow path (assuming complete mixing). Table 4 summarizes the fluoride concentrations for the various sources used in the load balance model. For the case of fluoride the background concentrations quoted in an earlier study (see RGC 1998) turned out to be slightly above the target concentrations observed downstream of the Questa tailings facility (c. Tables 4 and 5). For simplicity, the background concentrations were therefore set equal to the target concentrations.

The fluoride load balance strongly suggests that fluoride is chemically attenuated along the flow path. This result is consistent with groundwater quality observed in monitoring wells and springs which do not show fluoride concentrations significantly above background in any of the downstream monitoring wells (Figures 27-28) and/or springs (Figure 29). The amount of fluoride lost to chemical attenuation (expressed as a mass rate loss in kg per year) was estimated by adjusting this sink term until the target concentrations at the Molycorp boundary and/or at the discharge points near the Red River were met.

The estimated sink terms for fluoride are shown as negative numbers in the boxes representing the vadose zone of the fluoride load balance sheet (Figure 32). Accordingly, the total annual loss of fluoride from the system due to chemical attenuation (adsorption and/or precipitation) is estimated to be about 9380 kg/year. This sink term represents about 67% of the estimated total load of fluoride introduced into the system. Note that this sink term may also include some (as yet unspecified) storage in the unsaturated alluvial sediments (see section 7.2.2).

7.2.4 *Molybdenum Load Balance*

Figure 33 shows the estimated average annual load balance for molybdenum. The annual molybdenum load for each pathway is shown in kilograms per year. The values in brackets indicate the calculated molybdenum concentration for the particular flow path (assuming complete mixing). Table 4 summarizes the molybdenum concentrations for the various sources used in the load balance model. The background concentration for molybdenum was assumed to be zero, i.e. all molybdenum introduced into the system is derived from process water and/or tailings seepage.

The molybdenum load balance strongly suggests that molybdenum is chemically attenuated along the flow path. This result is consistent with groundwater quality observed in monitoring wells and springs showing molybdenum concentrations consistently much lower than in the tailings seepage in all downstream monitoring wells (Figures 27-28) and/or springs (Figure 29). The amount of molybdenum lost to chemical attenuation (expressed as a mass rate loss in kg per year) was estimated by adjusting this sink term until the target concentrations at the Molycorp boundary and/or at the discharge points near the Red River were met.

The estimated sink terms for molybdenum are shown as negative numbers in the boxes representing the vadose zone of the molybdenum load balance sheet (Figure 33). Accordingly, the total annual loss of molybdenum from the system due to chemical attenuation (adsorption and/or co-precipitation) is estimated to be about 3600 kg/year. This sink term represents about 54% of the estimated total load of molybdenum introduced into the system. As discussed previously, storage of tailings seepage in the unsaturated alluvial sediments may account for some of this loss in molybdenum.

7.2.5 *Manganese Load Balance*

Figure 34 shows the estimated average annual load balance for manganese. The annual manganese load for each pathway is shown in kilograms per year. The values in brackets indicate the calculated manganese concentration for the particular flow path (assuming complete mixing). Table 4 summarizes the manganese concentrations for the various sources used in the load balance model. Natural background concentrations of manganese in the deep volcanic aquifer were assumed to be zero as suggested by a number of samples taken in the Guadalupe Mountain area in the mid-1980s (Danes and Moore, 1987). However, no natural background concentrations were available for manganese in the shallow alluvial groundwater. For simplicity, manganese background concentrations in the shallow alluvial aquifer system were also assumed to be zero.

The manganese load balance suggests that manganese is being consumed in the vadose zone overlying the deep volcanic aquifer whereas it is being produced along the flow path in the shallow aquifer system (i.e. in the alluvial soils). An apparent source of manganese is required since the load of manganese removed with the interception system (715 kg per year based on outfall 002 data) is greater than the estimated load from old process water and fresh recharge water draining from the tailings (combined total of 599 kg per year). Unfortunately, no background concentrations of manganese in the shallow alluvial aquifer are available to estimate how much of this apparent source is due to natural infiltration water being intercepted in the seepage interception system.

Alternatively, the manganese not accounted for in the load balance could have been generated within the tailings. Tailings pore water collected in three boreholes from the base of the Section 36 impoundment showed an average manganese concentration of 4.3 mg/l, i.e. manganese concentrations significantly higher than both the observed tailings pond water quality (0.37 mg/l) and the assumed pore water concentration originating from precipitation (i.e. 2.2 mg/l as back-calculated from six leach extraction tests). The manganese load balance model was rerun assuming a combined input concentration of 4.3 mg/l manganese for all water passing through the tailings (regardless of its origin). With this higher source concentration manganese would have to be lost in the vadose zone of the shallow alluvial aquifer. The estimated sink for this scenario would be 2900 kg per year. This sensitivity run indicates that the load balance for manganese is very sensitive to the assumed input concentration.

7.3 Summary of Load Balance Analysis

The results of the water balance analysis were used to estimate annual load balances for four selected constituents (sulfate, fluoride, molybdenum and manganese). Source concentrations for process water infiltrating directly into volcanics and stored in the tailings were estimated from recent tailings pond water concentrations. Source concentrations for tailings pore water originating from precipitation were estimated from leach extraction tests performed on six tailings samples.

The load balance for the non-reactive constituent sulfate was used to estimate the degree of mixing of tailings seepage with groundwater in the shallow and deep aquifer systems, respectively. The sulfate load balance indicated only limited mixing with the shallow groundwater up to the Molycorp property boundary. In contrast, a large degree of mixing had to be postulated for tailings seepage entering the deep volcanic aquifer in order to match the observed sulfate concentrations in the deep volcanic aquifer at the Molycorp property boundary. Even larger groundwater flow rates (approaching the total groundwater flow estimated for the study region) had to be assumed to match the very low sulfate concentrations observed in springs discharging from the volcanic aquifer at the Red River (flow-weighted average of 71 mg/l). Sensitivity runs with the sulfate load balance model suggested that factors other than dilution must contribute to the very low sulfate concentrations in the deep volcanics. These factors likely include significant storage of tailings seepage in the unsaturated alluvial sediments beneath the tailings facility and a higher proportion of tailings seepage recharging the shallow alluvial aquifer. Alternatively, the infiltration rates estimated with the water balance method and/or the assumed source concentrations could be too high.

The load balance models for fluoride and molybdenum suggested significant chemical attenuation of these reactive constituents in the alluvial soils underlying the tailings facility amounting to 67% and 54% of the total load, respectively. The load balance model for manganese was inconclusive owing to the large uncertainty in the source concentration.

Sensitivity analyses with the non-reactive and reactive load models indicated that there is still significant uncertainty in components of the water balance (e.g. size of storage in the unsaturated zone, amount of deep underflow) as well as the assumed source concentrations, in particular some of the reactive constituents. As a result the estimated load balances for the four constituents sulfate, fluoride, molybdenum and manganese presented here are considered preliminary and should be viewed with caution. These preliminary load balances will be updated as part of the non-reactive and reactive load model for the entire Red River basin to be submitted in the Reports on Conservative and Reactive Load Models for Red River basin (due on December 15, 2000).

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Table 1 Summary of Tailings Storage Development

Year	Section 36	Section 35
1965	Dam 1 to 7425 ft elevation (starter dam)	---
1966	Dam 1 to 7460 ft elevation	---
1967	Dam 1 to 7484 ft elevation	---
1968	Dam 1 to 7500 ft elevation	---
1969	Dam 1 to 7520 ft elevation Dam 2 to 7520 ft elevation	---
1970	---	---
1971	Dam 1 to 7525 ft elevation	Dam 4 to 7440 ft elevation (starter dam)
1972	---	Dam 4 to 7460 ft elevation
1973	---	i) Dam 4 to 7478 ft elevation ii) Dam 3A to 7532 ft elevation (average)
1974	---	---
1975	i) Dam 1C to 7560 ft elevation by cyclones ii) Dam 1B, 2A to 7560 ft elevation	Dam 4 to 7505 ft elevation
1976-1978	---	---
1979-1980	Dam 2B to 7584 ft elevation by cyclones	Dam 4 to 7512 ft elevation
1981-1982	Dams 1C, 1B, 2A and Separator Dike to 7584 ft elevation	Dam 4 to 7520 ft elevation
1983-1989	---	---
1990	---	Dam 5A to 7525 ft elevation (starter dam)
1991-1995	---	---
1996	---	Dam 5A to 7545 ft elevation

Table 2 Geotechnical Characteristics of Deposited Tailings

Item	Value	Comment
Specific gravity (G_s)	2.65	Average of four tests conducted on samples obtained from boreholes in the vicinity of Dam 1C (Geocon, 1982).
Dry density ($M_S/(V_V+V_S)$)	92 lb/ft^3	Average of 100 tests on samples obtained from boreholes put down through the tailings deposits in Sections 35 and 36 (Geocon, 1982).
Saturated water content (M_W/M_S)	28.2%	Average of 27 tests on samples taken below the phreatic surface in boreholes in the vicinity of Dam 1C (Geocon, 1982). Given a specific gravity of 2.65, this is equivalent to a dry density of 94.7 ft^3/s.

Notes: M_W and M_S are mass of water and mass of solids, respectively.
V_V and V_S are volumes of voids and solids, respectively.

Table 3. Summary Statistics for Decant and Seepage Water Quality

		Outfall 001 (decant)	Seepage Barrier 002		Seepage Barrier 003		Outfall 002
		1975-1982	1975-1982	1983-1985	1975-1982	1983-1985	1988-1999
pH	Average	7.52	7.51	7.50	8.04	7.88	7.57
	Standard Deviation	0.33	0.20	0.17	0.29	0.14	0.19
SO_4 (mg/l)	Average	1199	723	855	918	1092	-
	Standard Deviation	327	110	104	177	142	-
F (mg/l)	Average	2.41	2.44	2.13	0.62	0.54	1.80
	Standard Deviation	0.45	0.47	0.13	0.14	0.09	0.25
Mo (mg/l)	Average	2.11	2.96	2.69	0.06	0.19	2.23
	Standard Deviation	0.61	0.66	0.34	0.27	0.42	0.31
Mn (mg/l)	Average	0.44	1.23	1.37	0.08	0.05	1.64
	Standard Deviation	0.33	0.36	0.21	0.21	0.03	0.21

Table 4. Source Concentrations used as input to Load Balance Model (all in mg/l).

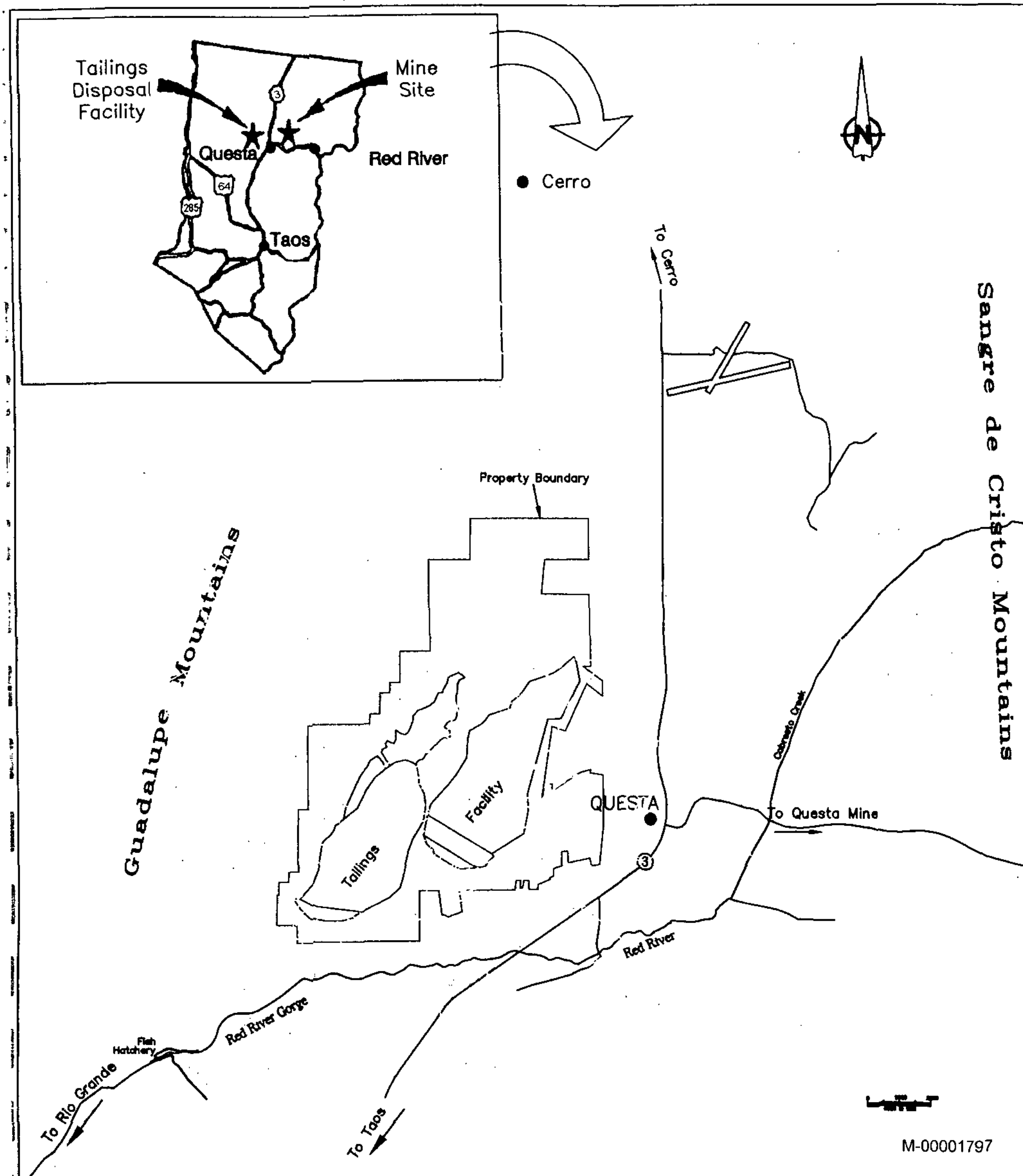
	SO4	F	Mo	Mn
Background Concentrations [(1)]				
- Shallow alluvial groundwater system	20	0.8	0	0
- Deep volcanic groundwater system	20	1.15	0	0
Seepage Losses of Process Water at Surface [(2)]	860	4.8	2.2	0.12
"Old" Process Water stored in Tailings Deposit [(3)]	1050	4.7	2.1	0.37
Tailings Porewater originating from Precipitation [(4)]	2466	2.2	5.2	3.4

Notes:
[(1)] see RGC, 1998 (table 2.5); if background concentrations were greater than downstream target concentrations (Table 5) then the latter estimate was taken as background
[(2)] median value of all tailings pond samples collected between 1997 and 1999
[(3)] average value of tailings pond samples collected between 1997 and 1999
[(4)] backcalculated from six leach extraction tests on Questa tailings (see Wels et al, 2000).

Table 5. Target Concentrations used for Load Balance Model (all in mg/l).

	SO4	F	Mo	Mn
Target Concentrations at Molycorp boundary				
shallow alluvial aquifer [1]	569	0.41	0.14	0.18
deep volcanic aquifer [2]	147	0.93	0.14	0.01
Target Concentrations at discharge point near Red River				
shallow alluvial aquifer ("cold springs") [3]	83	0.70	0.01	0.02
deep volcanic aquifer ("warm springs") [3]	64	1.02	0.02	0.01

Notes:
[1] average concentrations in monitoring wells in shallow alluvial aquifer located downstream of seepage interception system (MW-1, MW-2, MW-3, MW-9A and MW-14) for period fall of 1993 to spring 2000
[2] average concentrations in monitoring wells in deep volcanic aquifer located downstream of Questa tailings facility (MW-11 and MW-13) for period fall of 1993 to spring 2000
[3] average concentrations for period fall of 1993 to spring 2000



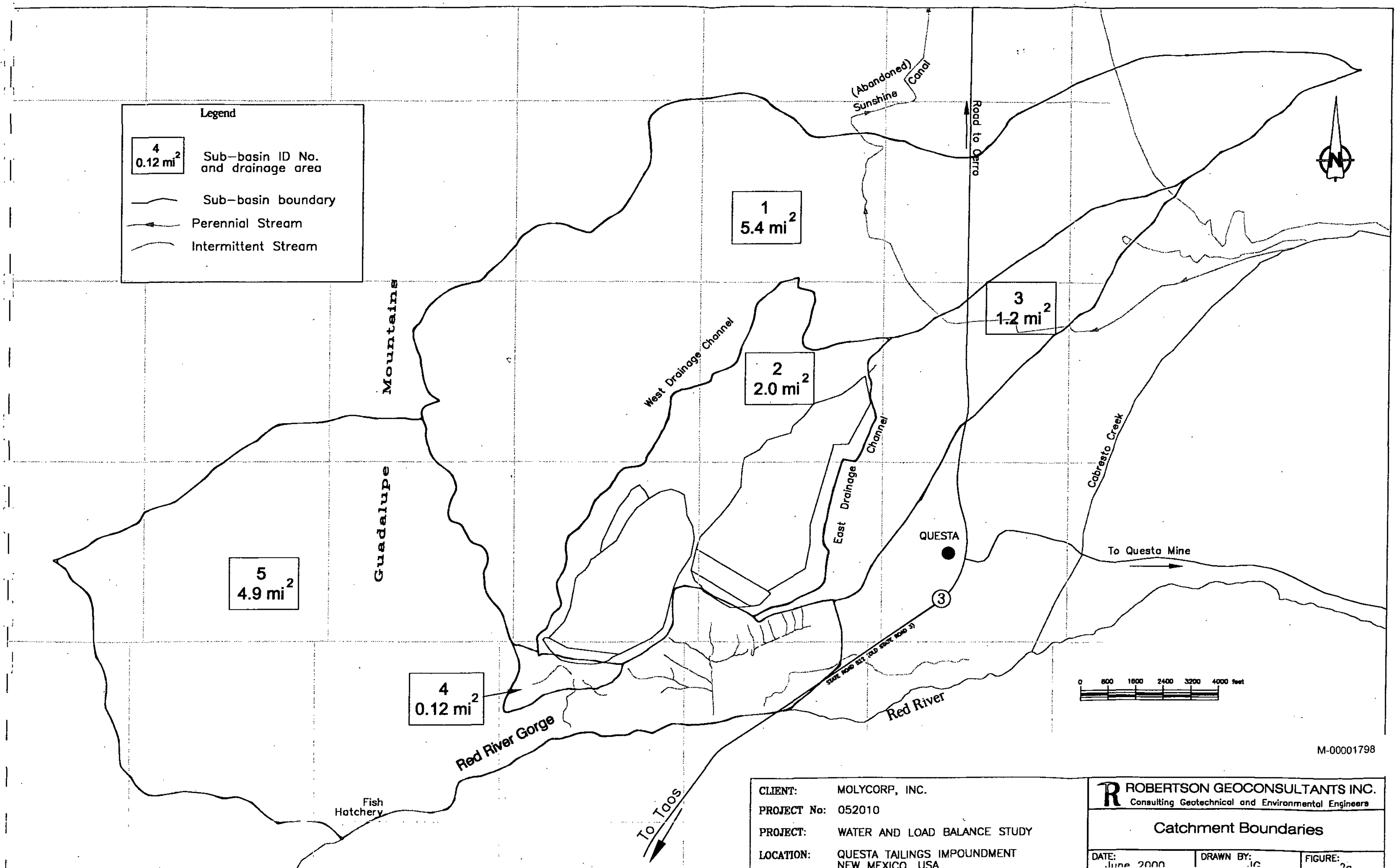
M-00001797

CLIENT:	MOLYCORP, INC.
PROJECT No:	052010
PROJECT:	WATER AND LOAD BALANCE STUDY
LOCATION:	QUESTA TAILINGS FACILITY NEW MEXICO, USA

ROBERTSON GEOCONSULTANTS INC.
Consulting Geotechnical and Environmental Engineers

Location Map

DATE:	DRAWN BY:	FIGURE:
June 2000	JG	1



CLIENT: MOLYCORP, INC.
PROJECT No: 052010
PROJECT: WATER AND LOAD BALANCE STUDY
LOCATION: QUESTA TAILINGS IMPOUNDMENT NEW MEXICO, USA

ROBERTSON GEOCONSULTANTS INC.
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Catchment Boundaries

DATE: June 2000
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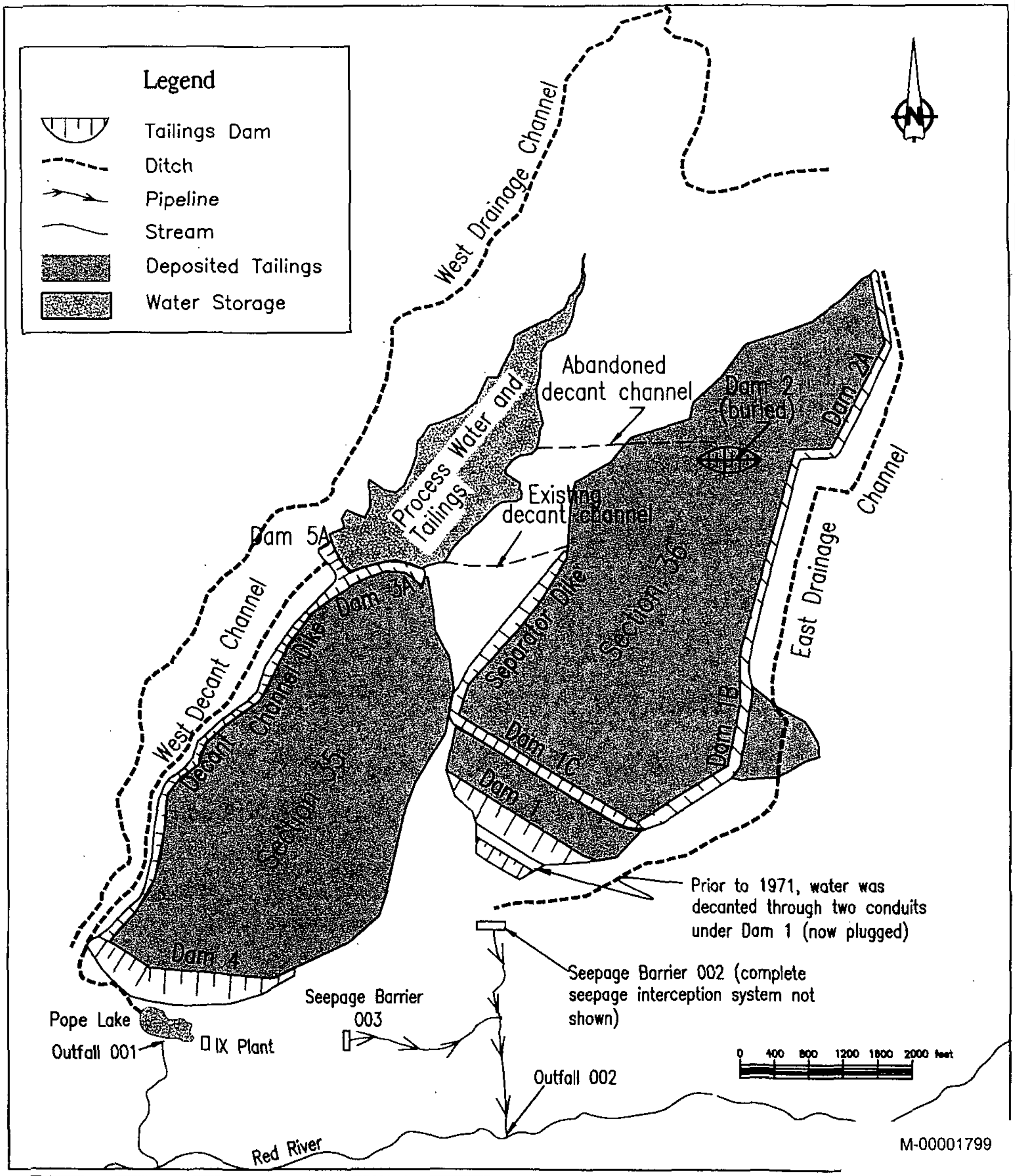
FIGURE:



M-00001799

CLIENT:	MOLYCORP, INC.
PROJECT No:	052010
PROJECT:	WATER AND LOAD BALANCE STUDY
LOCATION:	QUESTA TAILINGS FACILITY NEW MEXICO, USA

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Schematic of Tailings Storage Facility

DATE:	DRAWN BY:	FIGURE:
Jun 2000	JG	2b

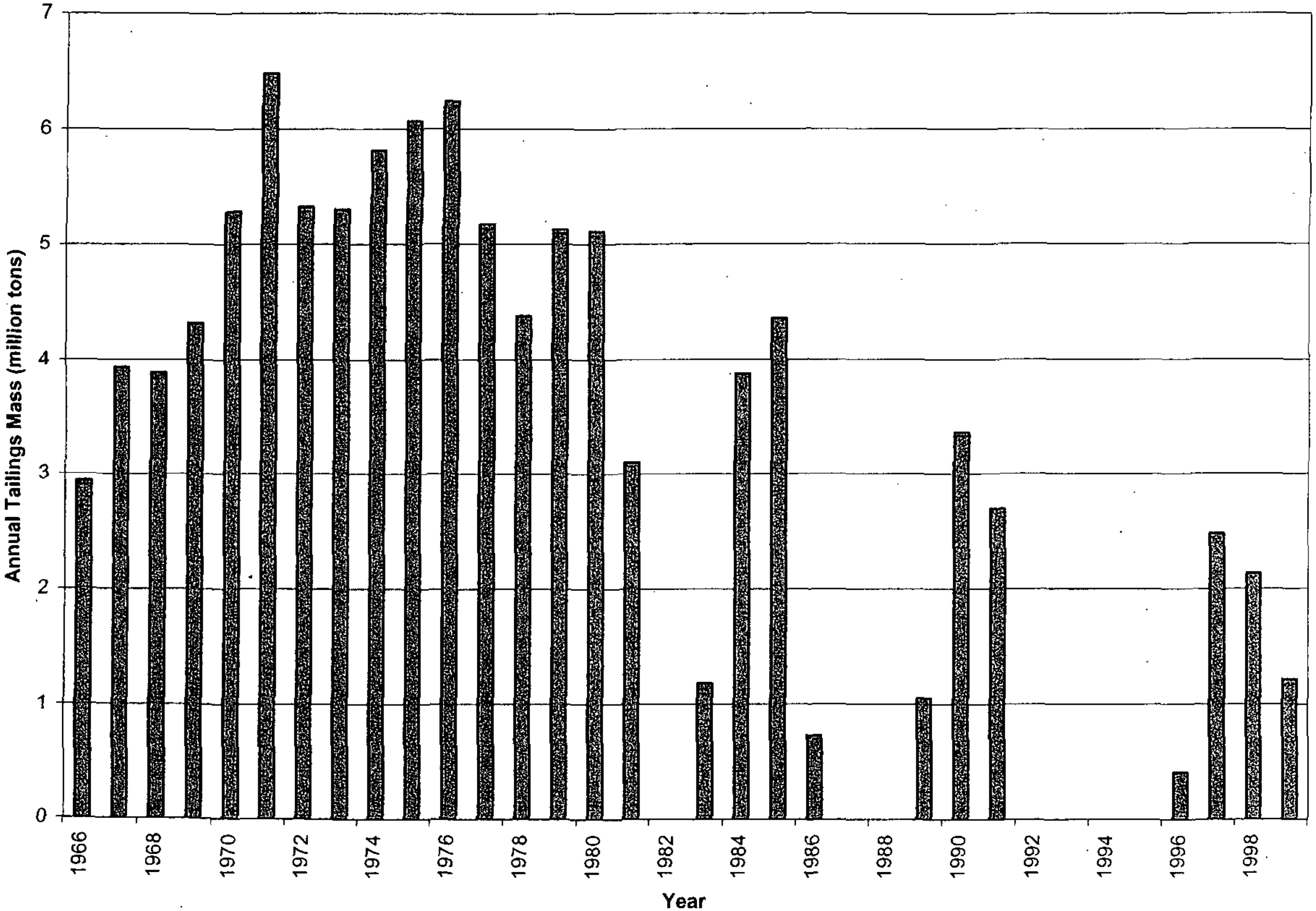


Figure 3. Annual Tailings Mass Stored in the Molycorp Tailings Impoundment

M-00001800

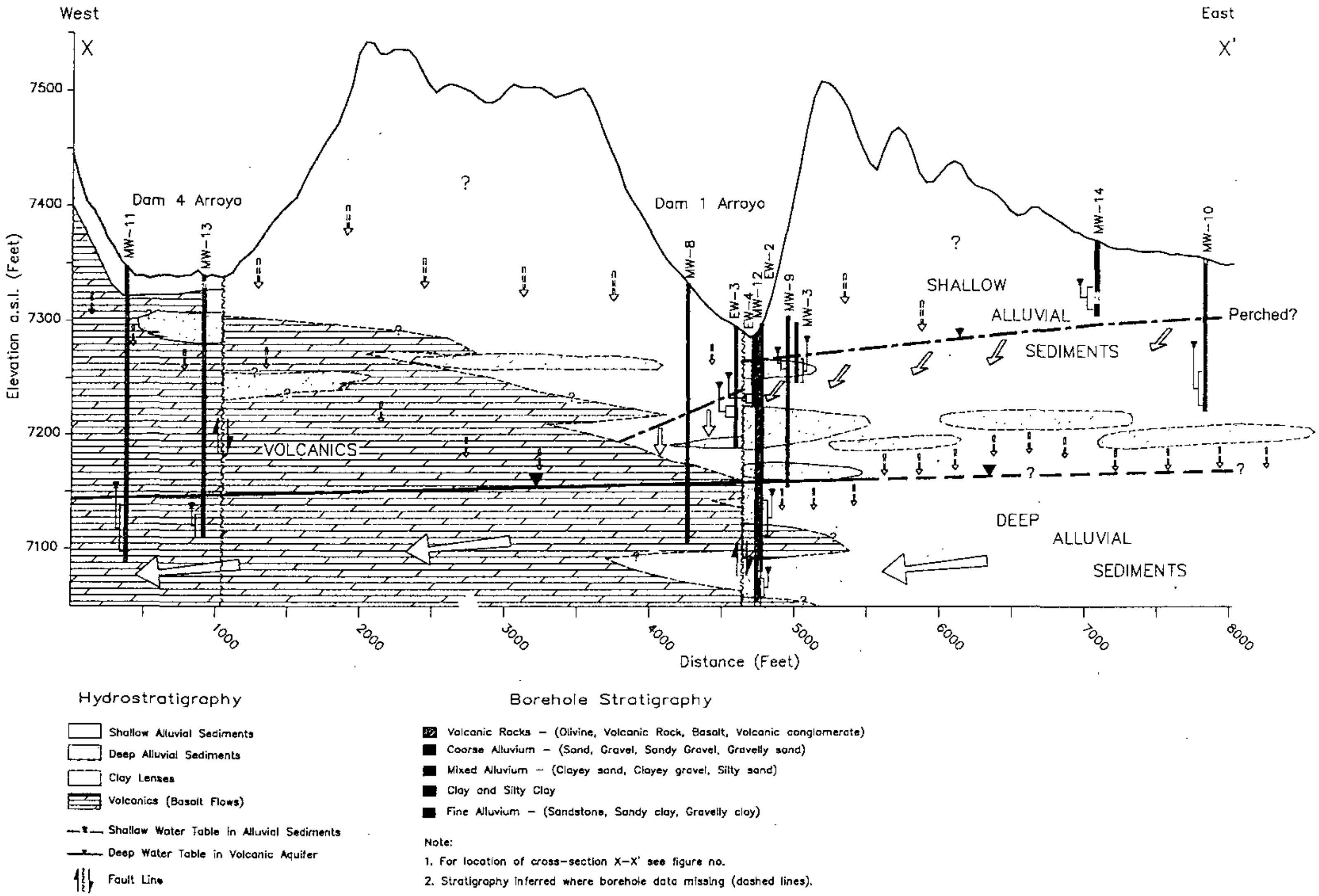


Figure 4a. Idealized cross-section showing geology and hydrostratigraphy (see Figure 1 for location).

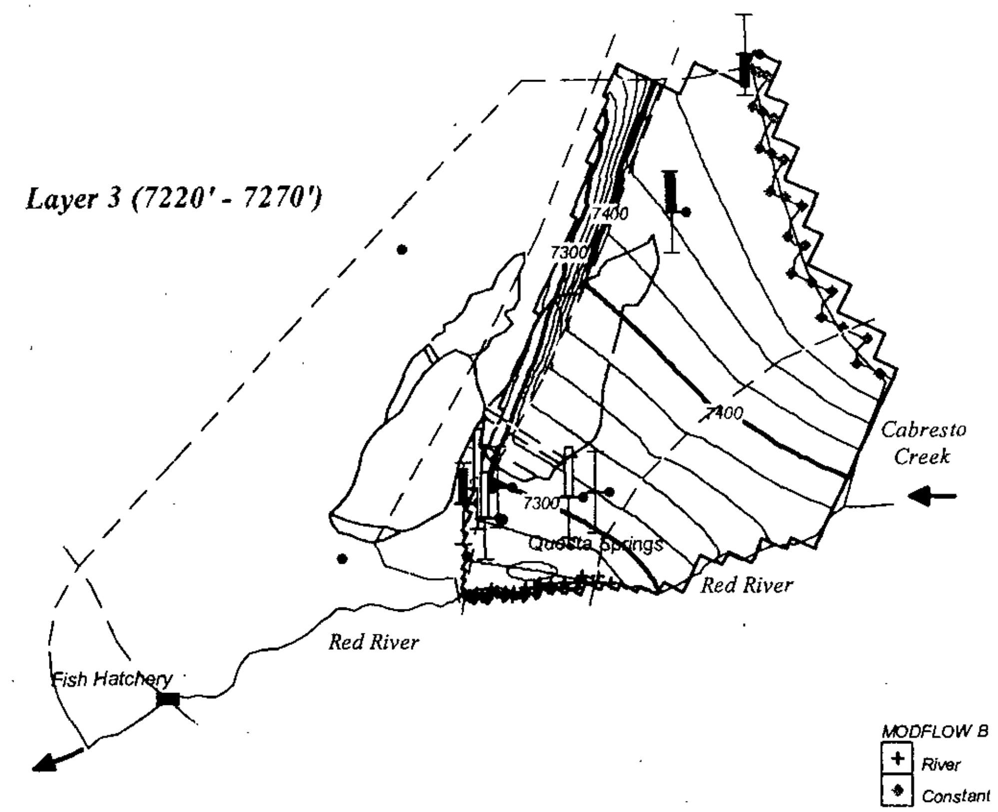


Figure 4b. Simulated hydraulic heads for upper aquifer system.

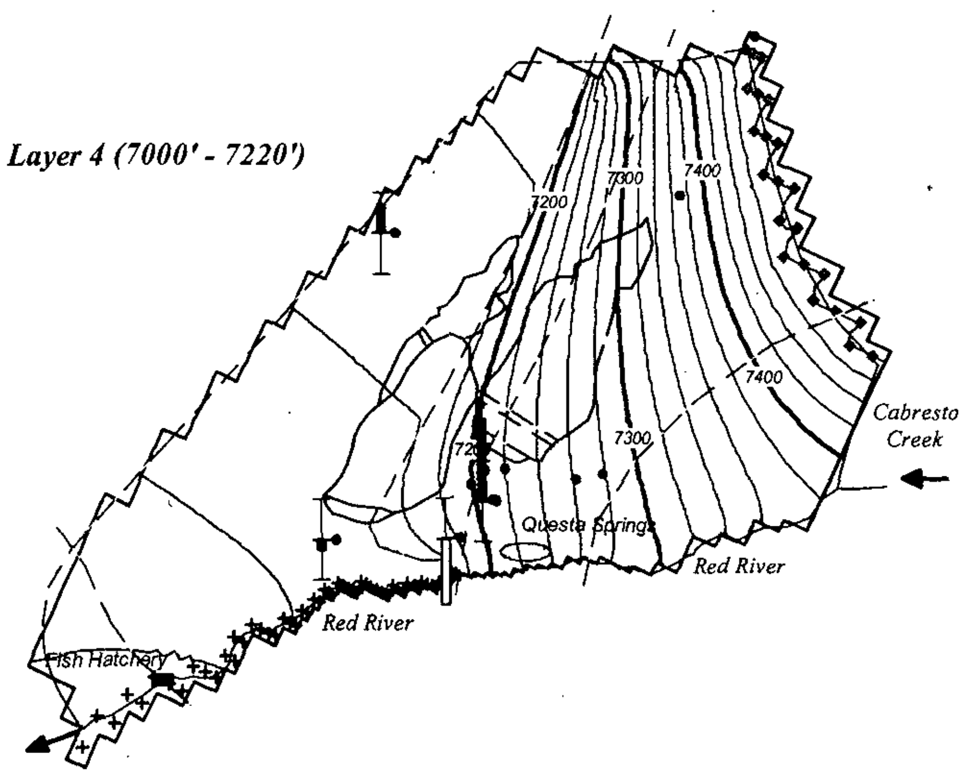
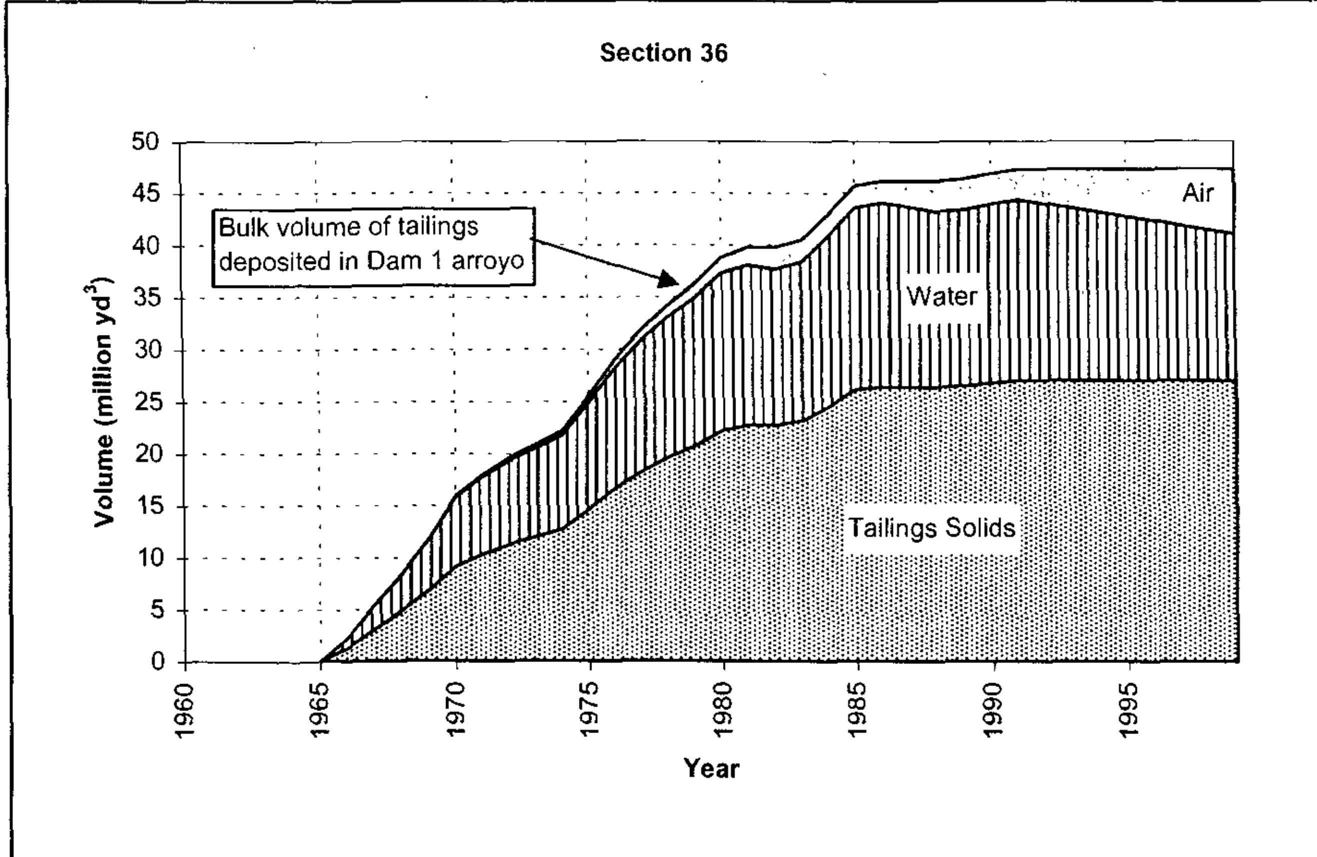


Figure 4c. Simulated hydraulic heads for lower aquifer system.



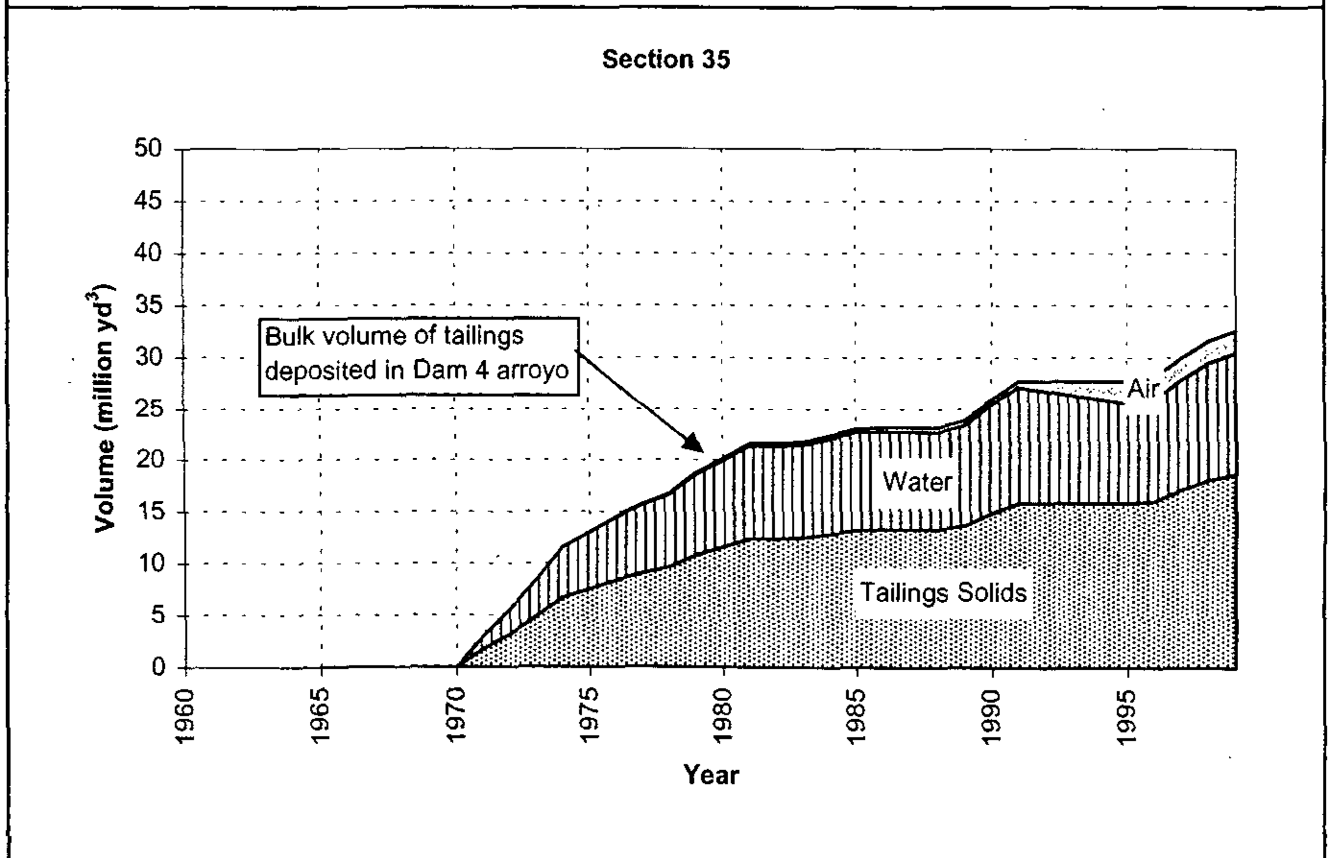
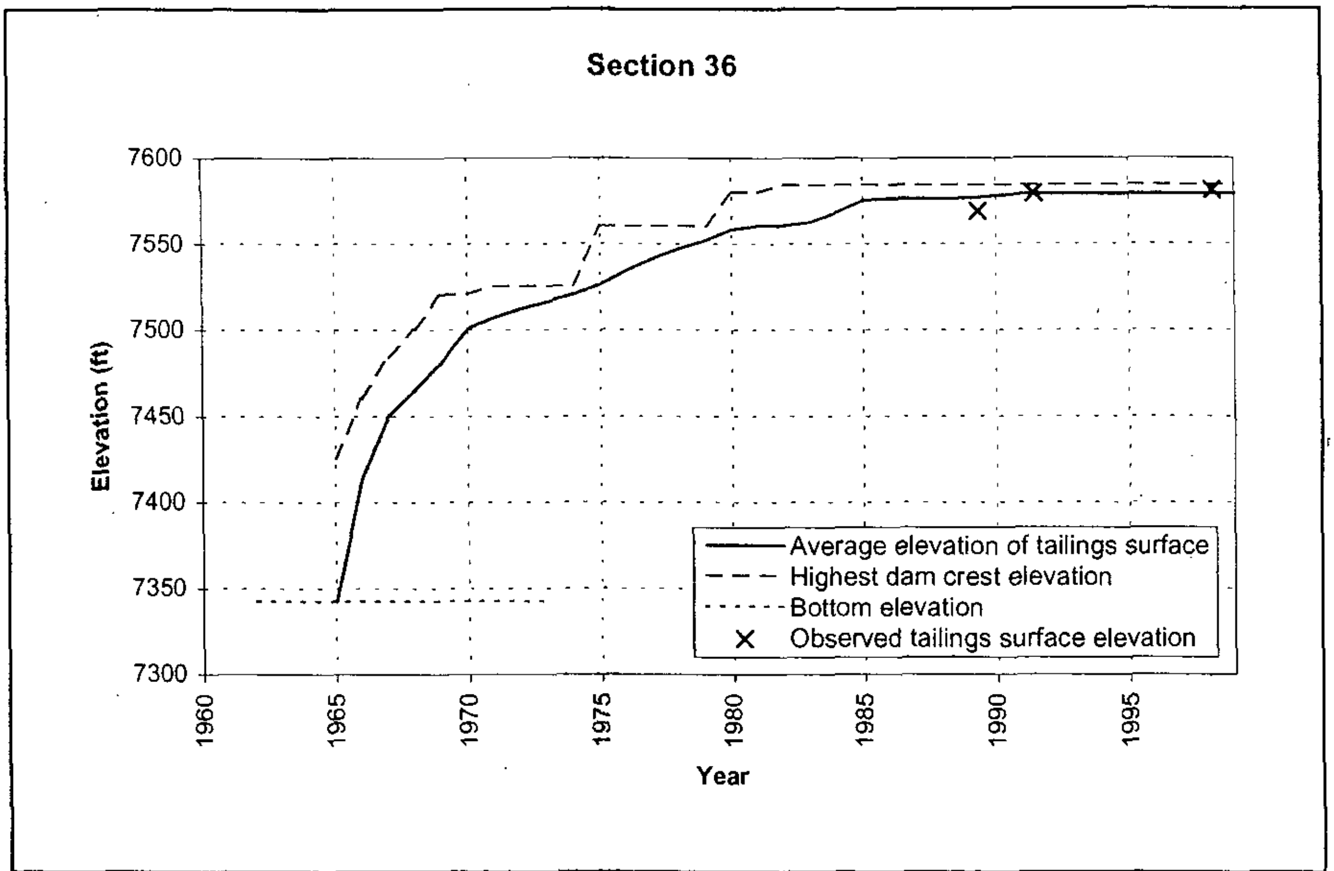


Figure 5. Estimated Volumes of Deposited Tailings for Period 1966 to 1999



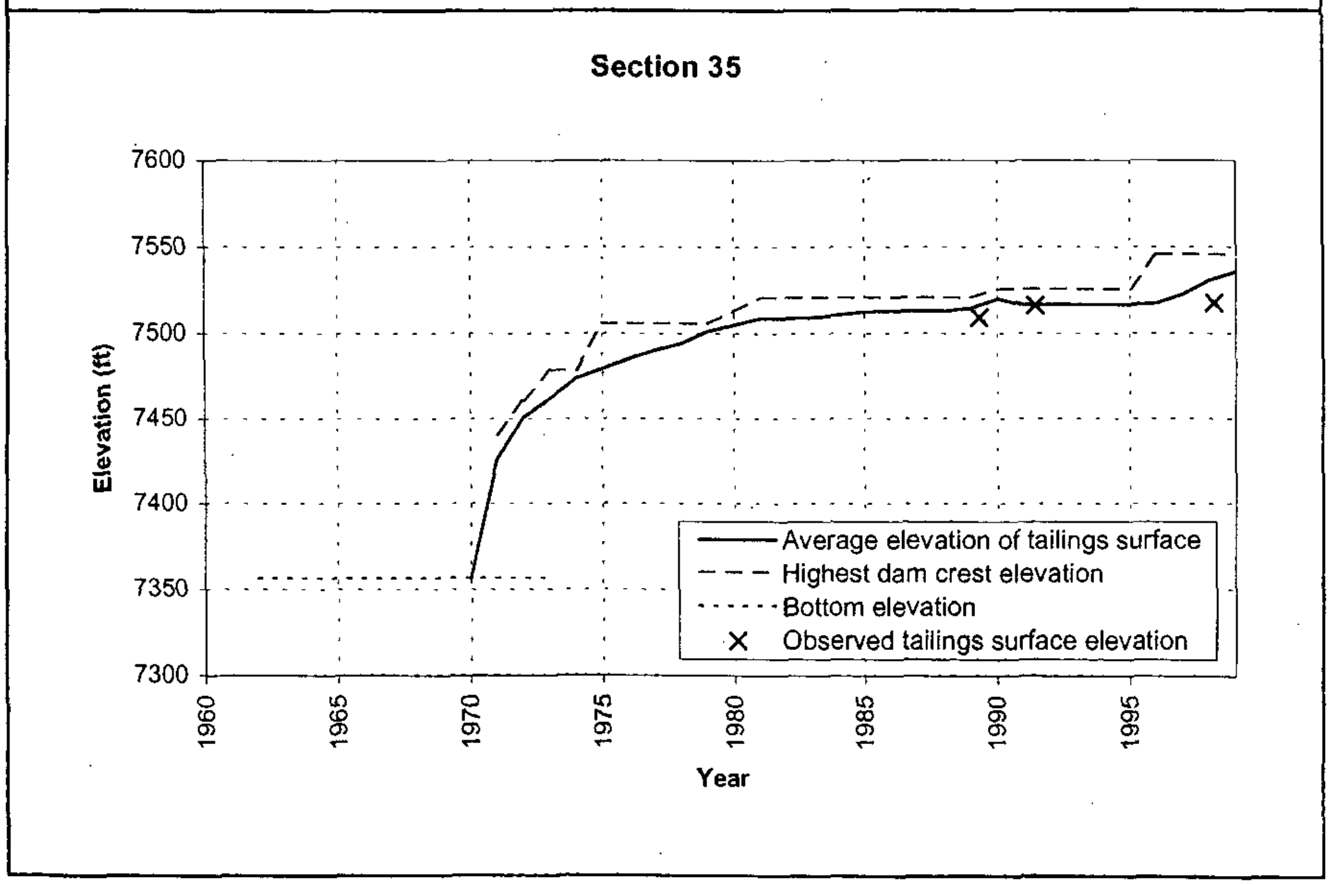


Figure 6. Estimated Tailings Surface Elevations for Period 1966 to 1999

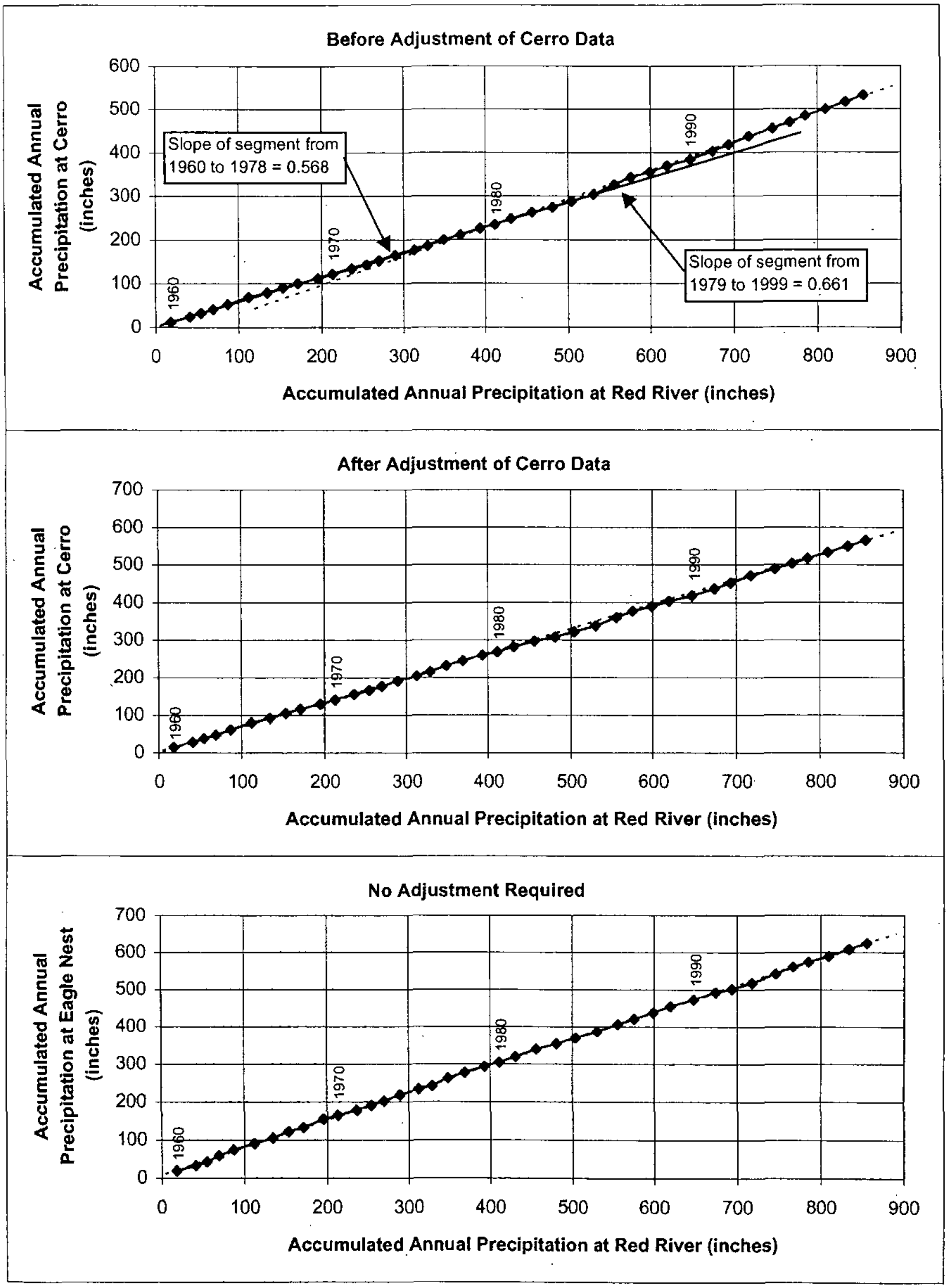
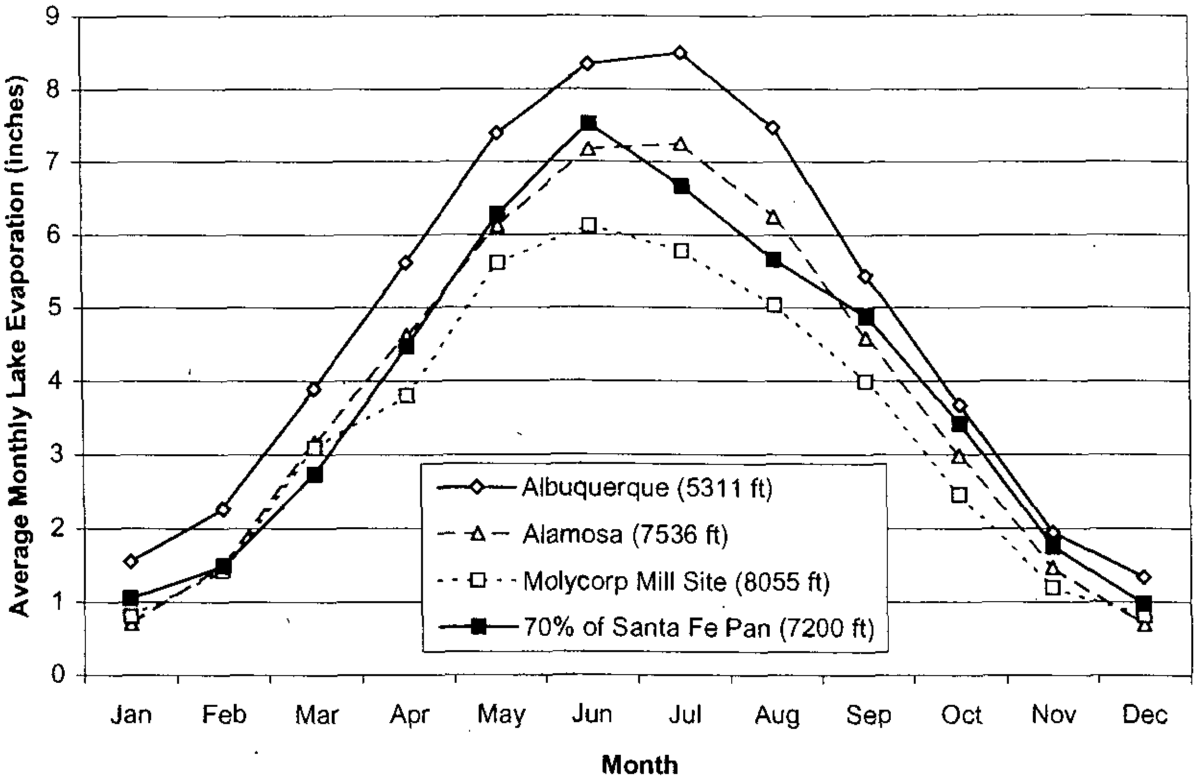


Figure 7. Adjustment of Precipitation Data for Cerro



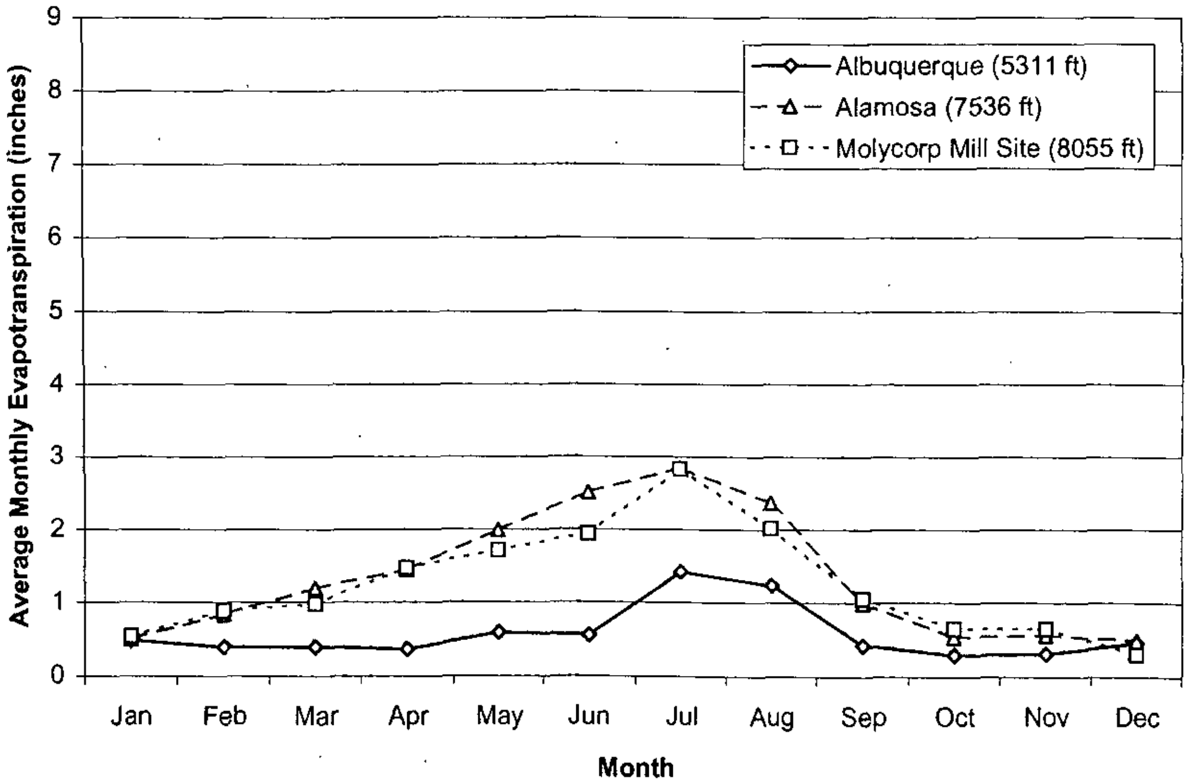


Figure 8. Estimated Lake Evaporation and Evapotranspiration at Regional Climate Stations

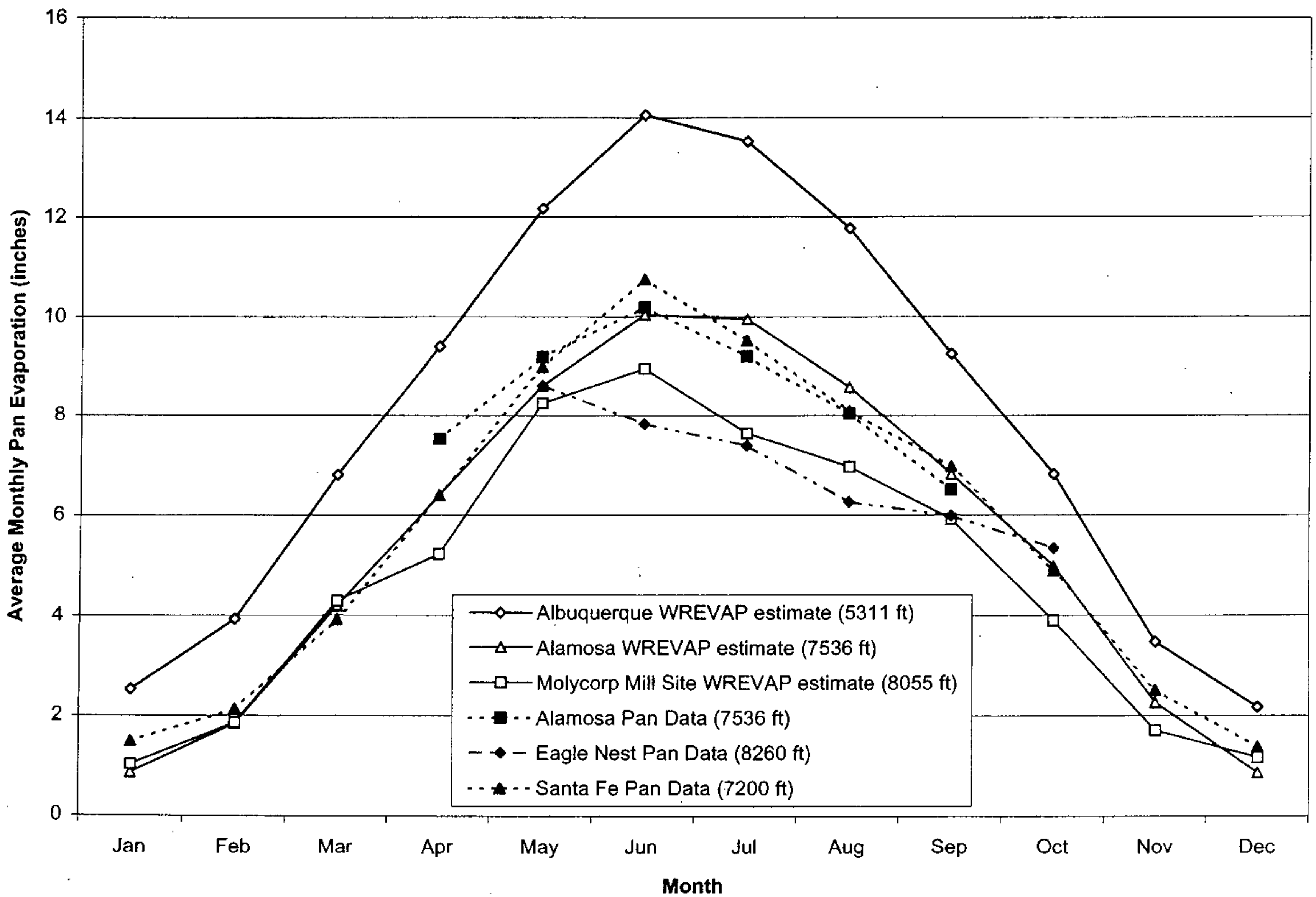
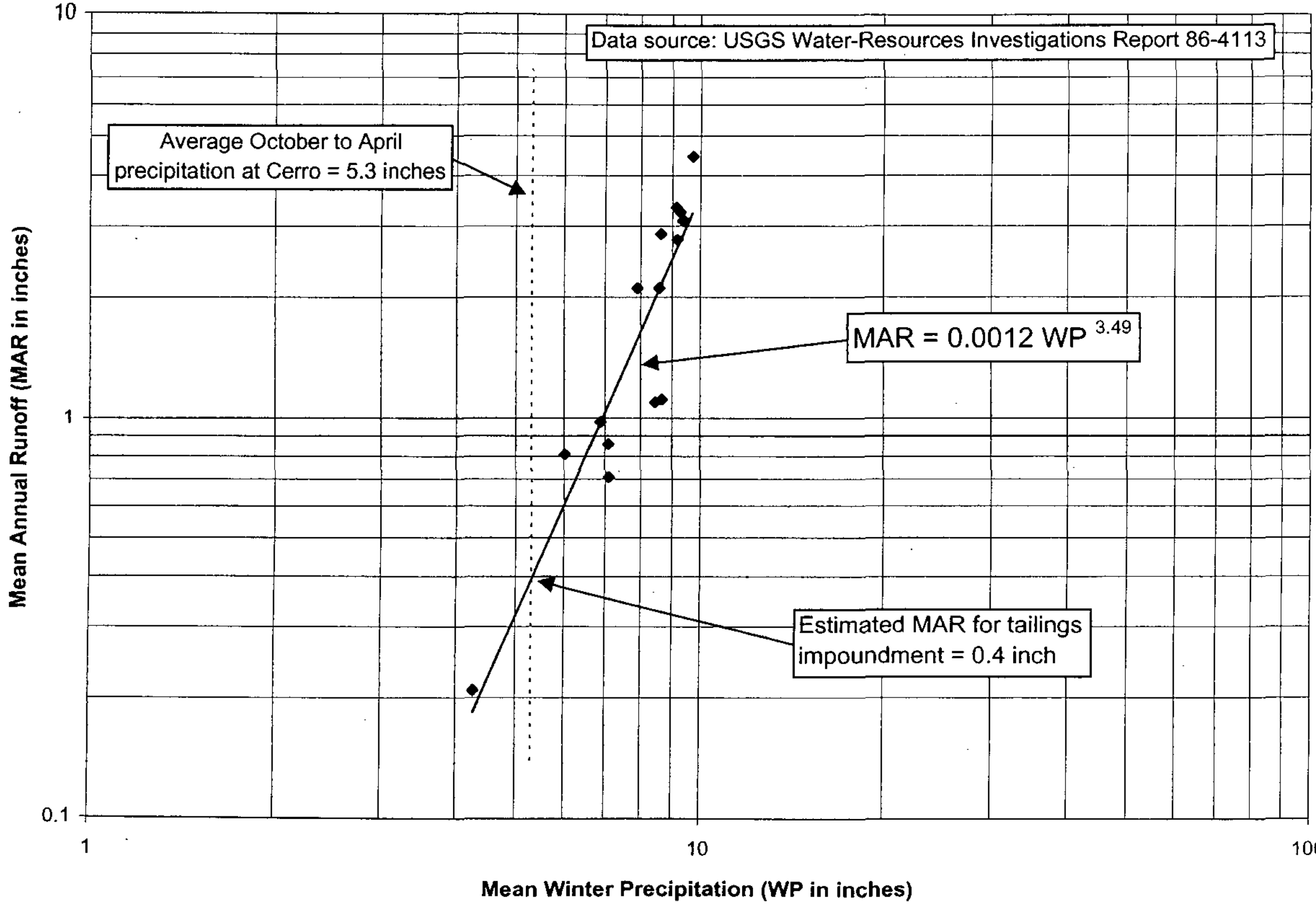


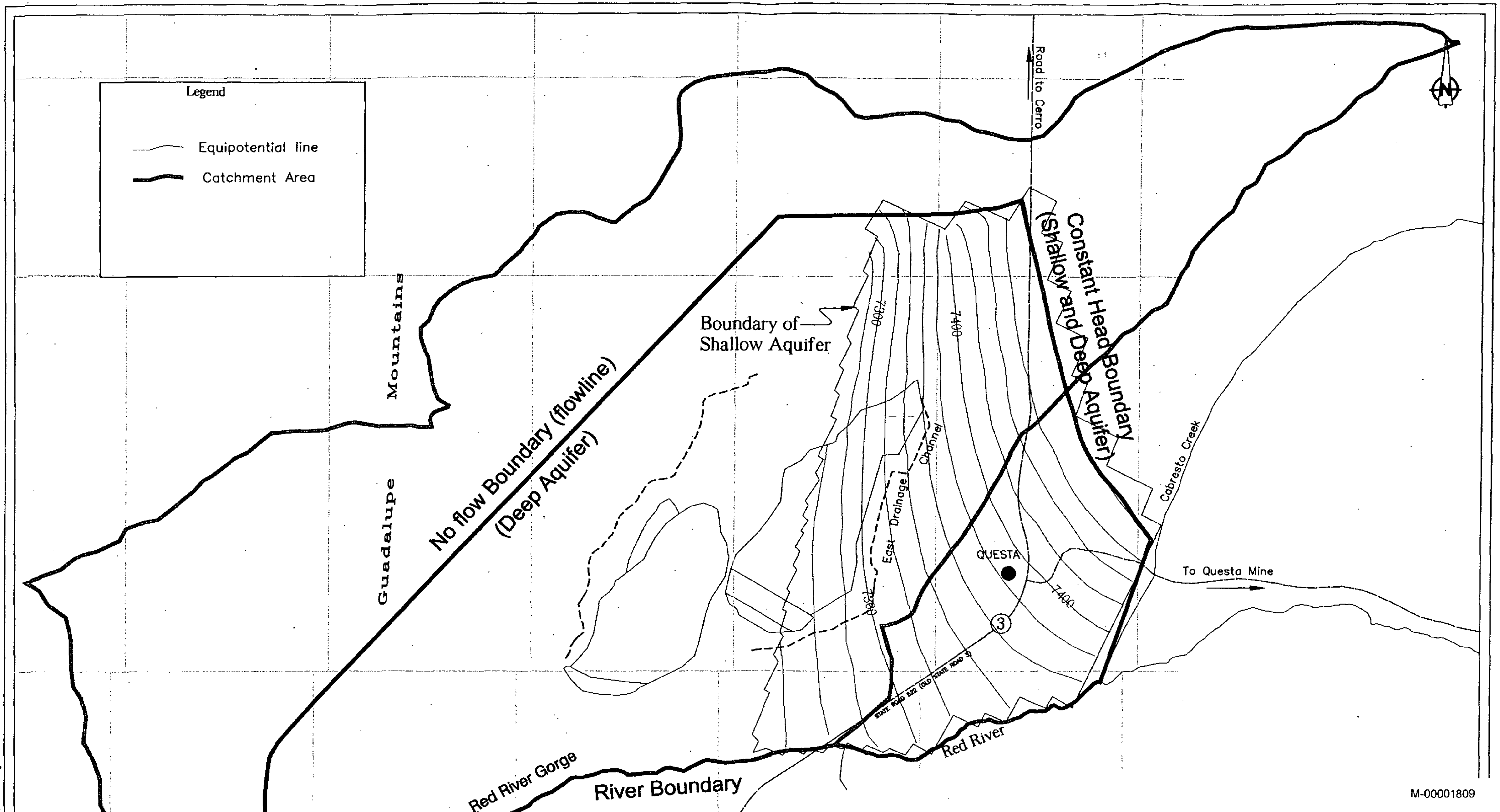
Figure 9. Comparison of Observed and WREVAP-Estimated Pan Evaporations

M-00001807



M-00001808

Figure 10. Regional Relationship Between Mean Annual Runoff and Mean Winter Precipitation



CLIENT:	MOLYCORP, INC.
PROJECT No:	052010
PROJECT:	WATER AND LOAD BALANCE STUDY
LOCATION:	QUESTA TAILINGS FACILITY NEW MEXICO, USA

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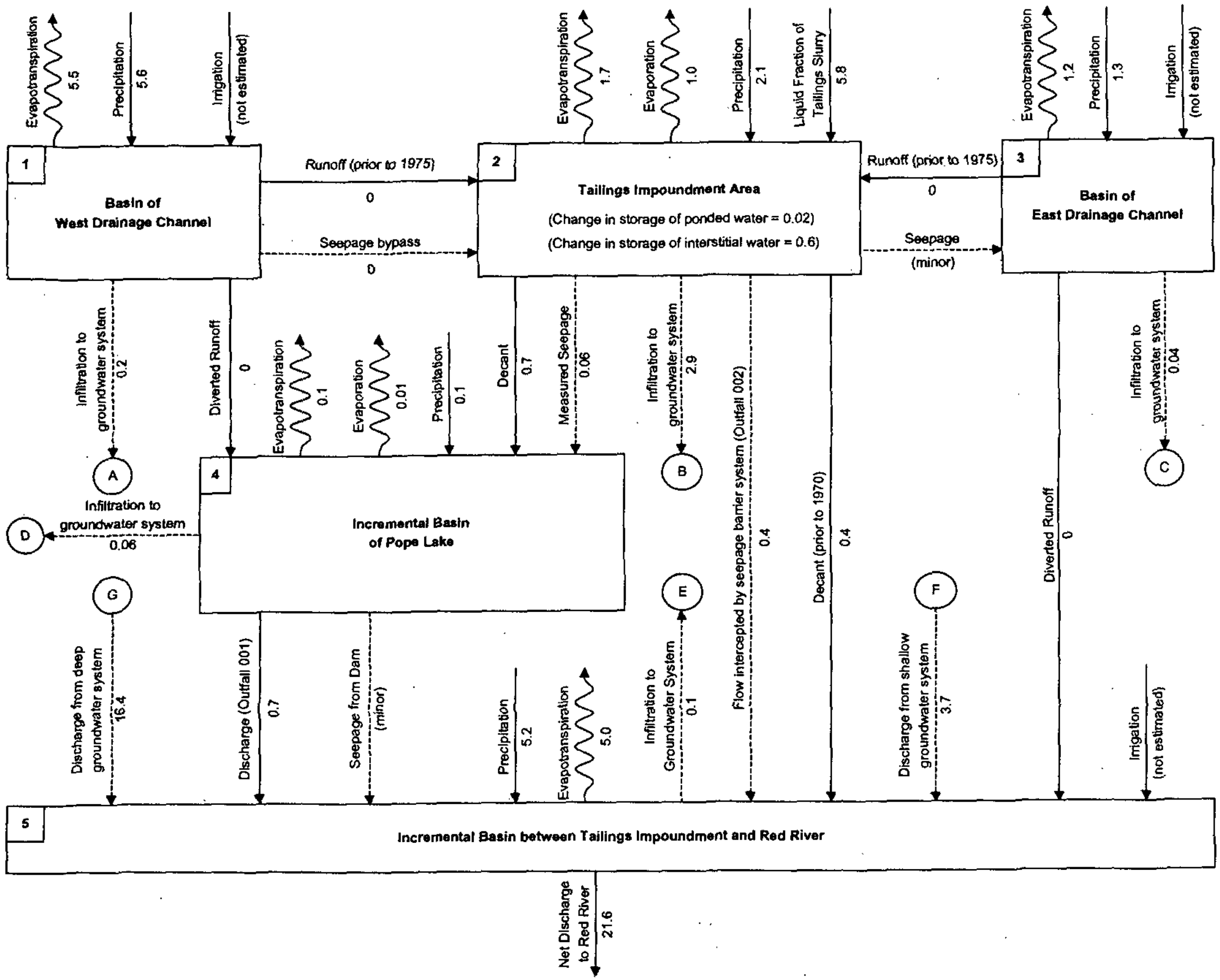
Surface Water and Groundwater Boundaries for Load Water Balance Analysis

DATE:	DRAWN BY:	FIGURE:
June 2000	JG	11



M-00001810

Figure 12a. Estimated Average Annual Water Balance for Period 1966 to 1999 (ft^3/s)

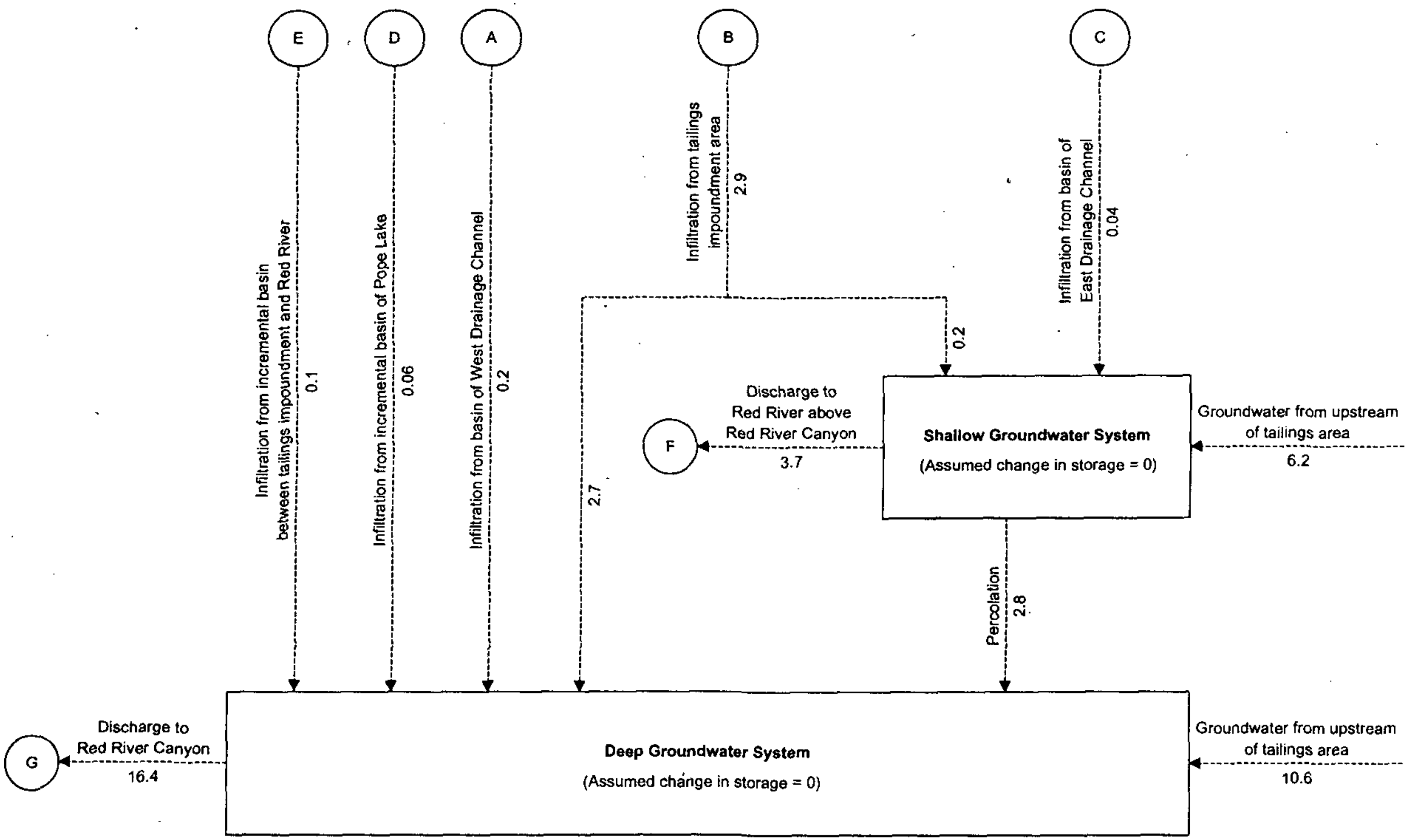
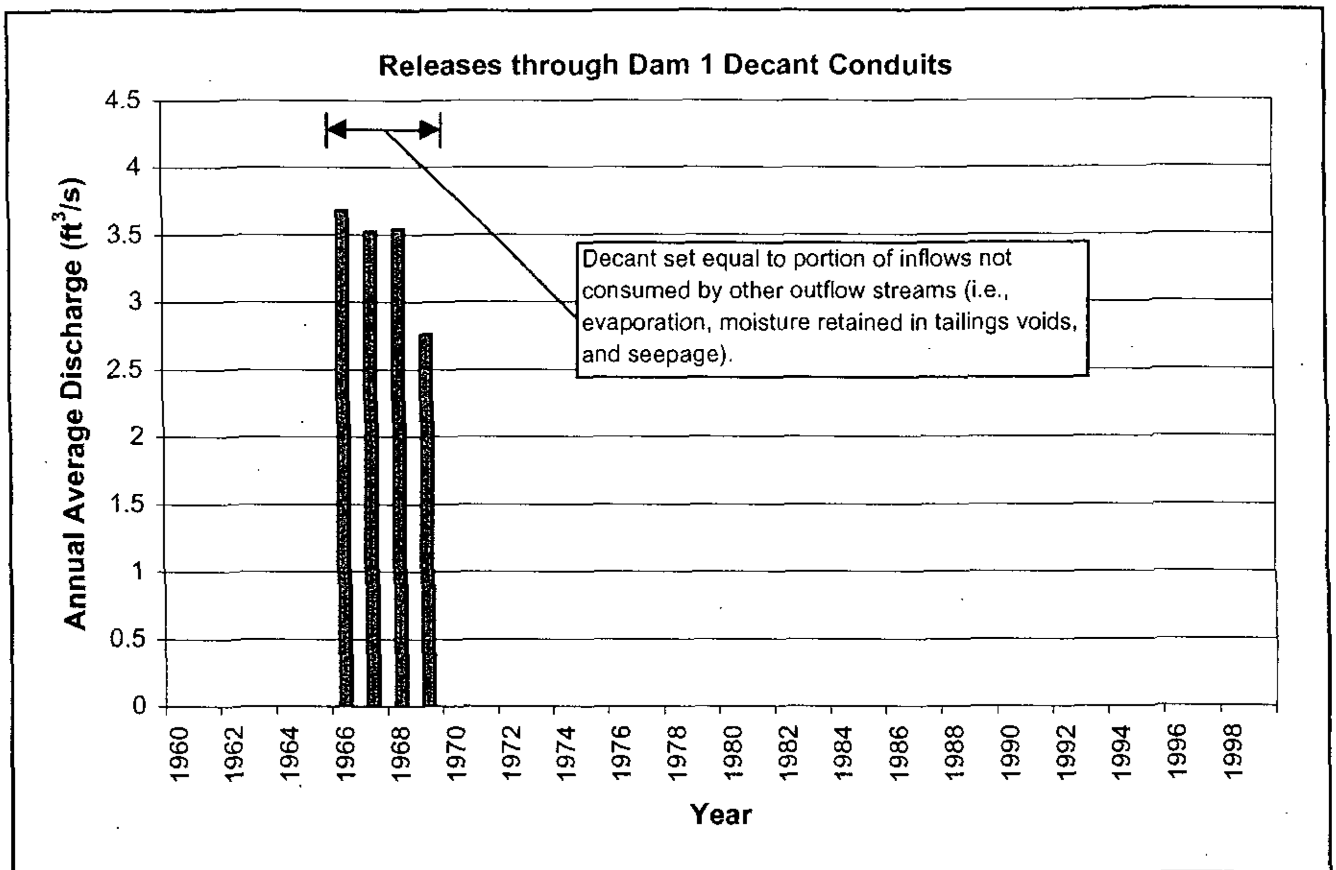


Figure 12b. Estimated Average Annual Water Balance for Period 1966 to 1999 (ft^3/s)

M-0001811



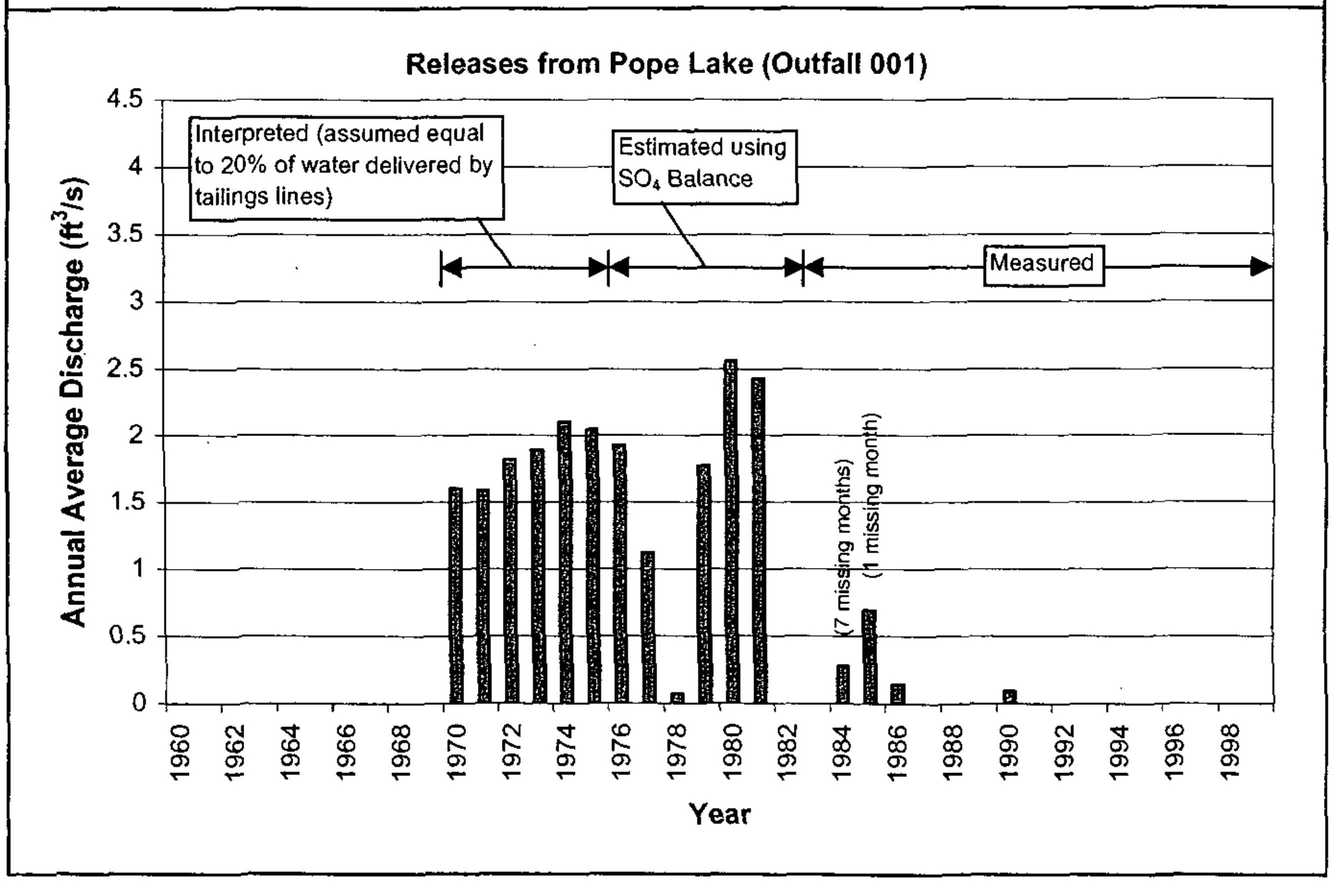


Figure 13. Reconstructed Record of Decant Flows from Tailings Impoundment for 1966 to 1999

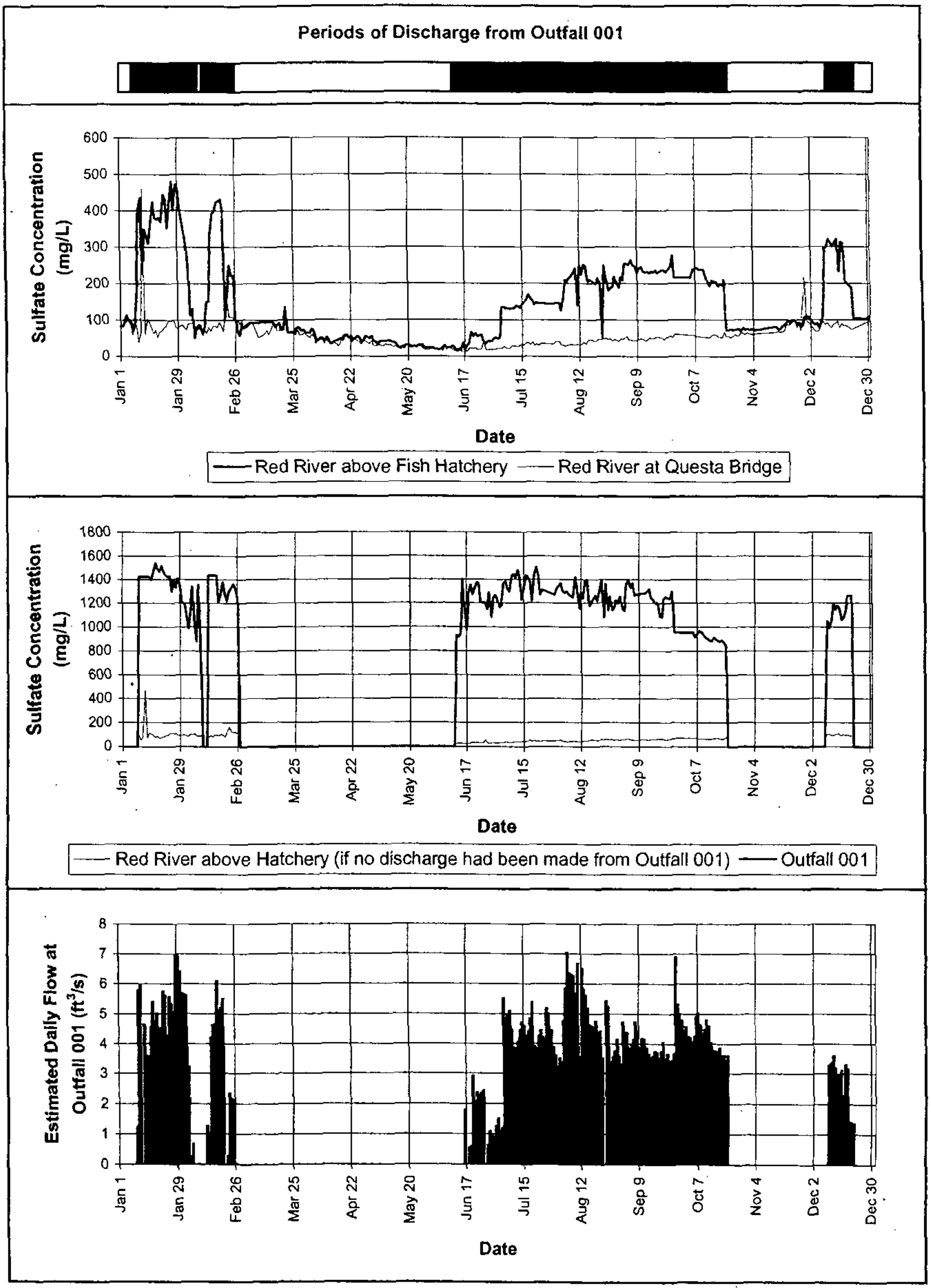
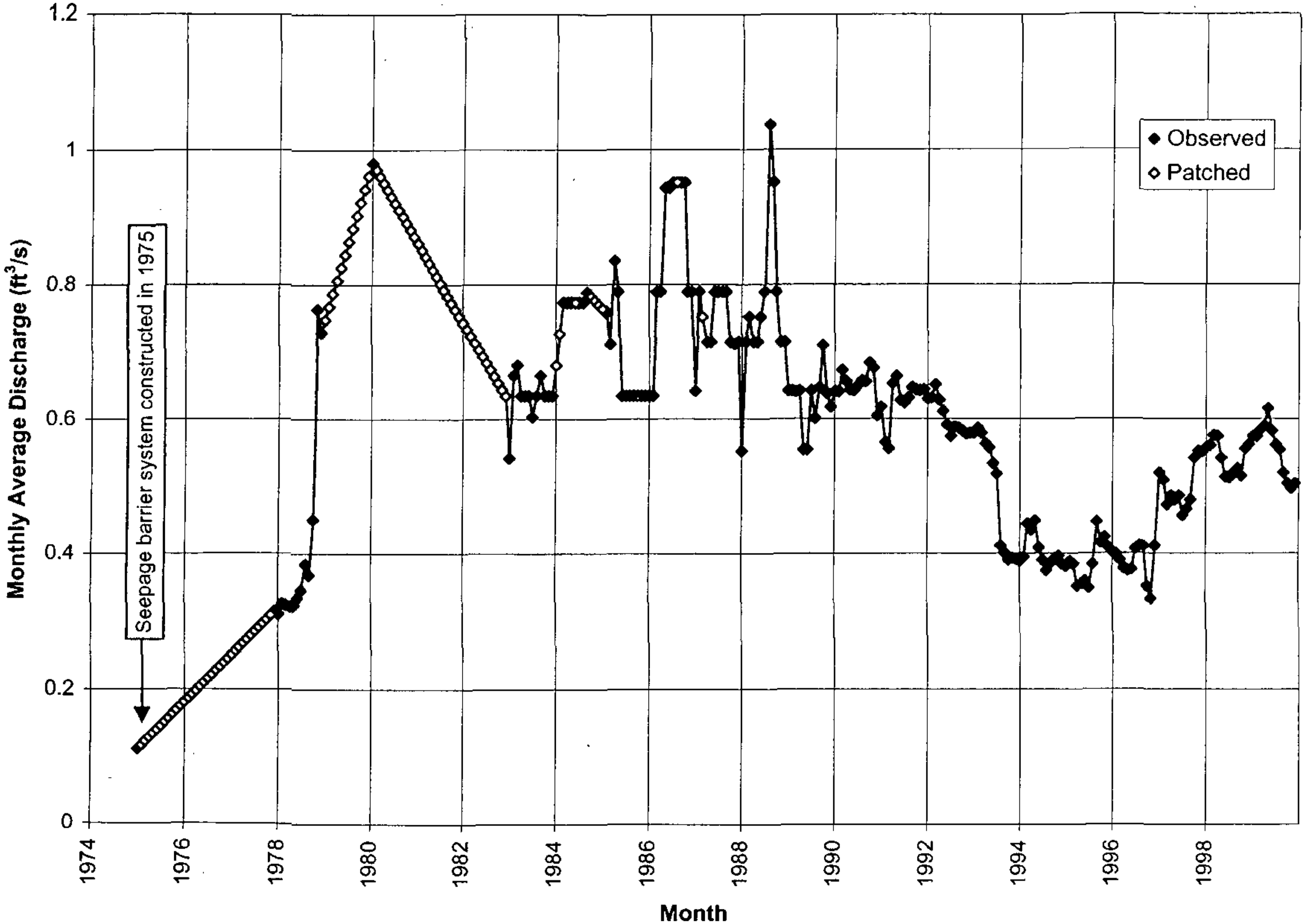


Figure 14. Method Used to Estimate Outfall 001 Flows During 1976



M-00001814

Figure 15. Reconstructed Record of Flows Intercepted by Seepage Barrier System for Period 1975 to 1999

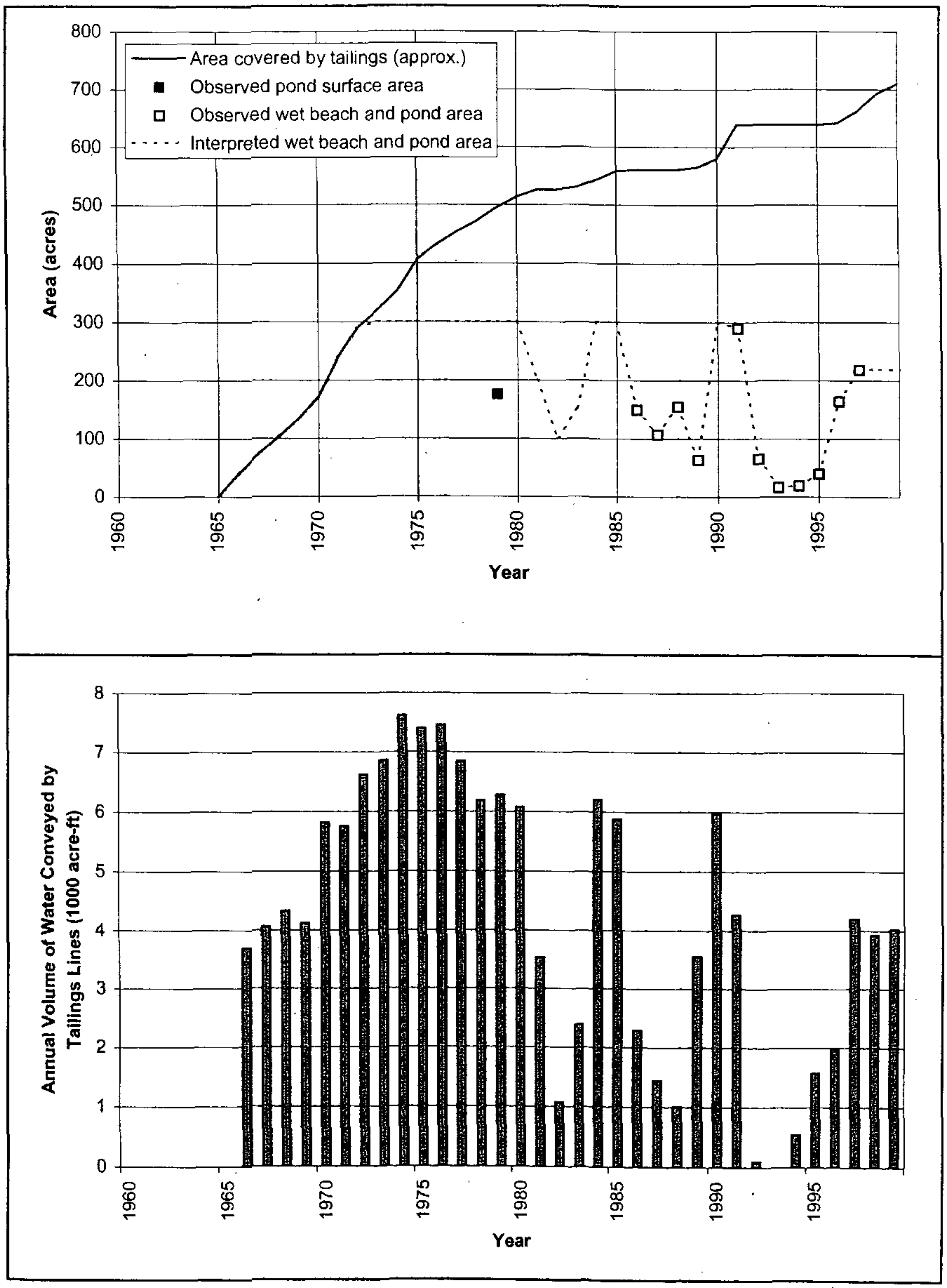


Figure 16. Estimated Wetted Surface Areas in Tailings Impoundment for Period 1966 to 1999

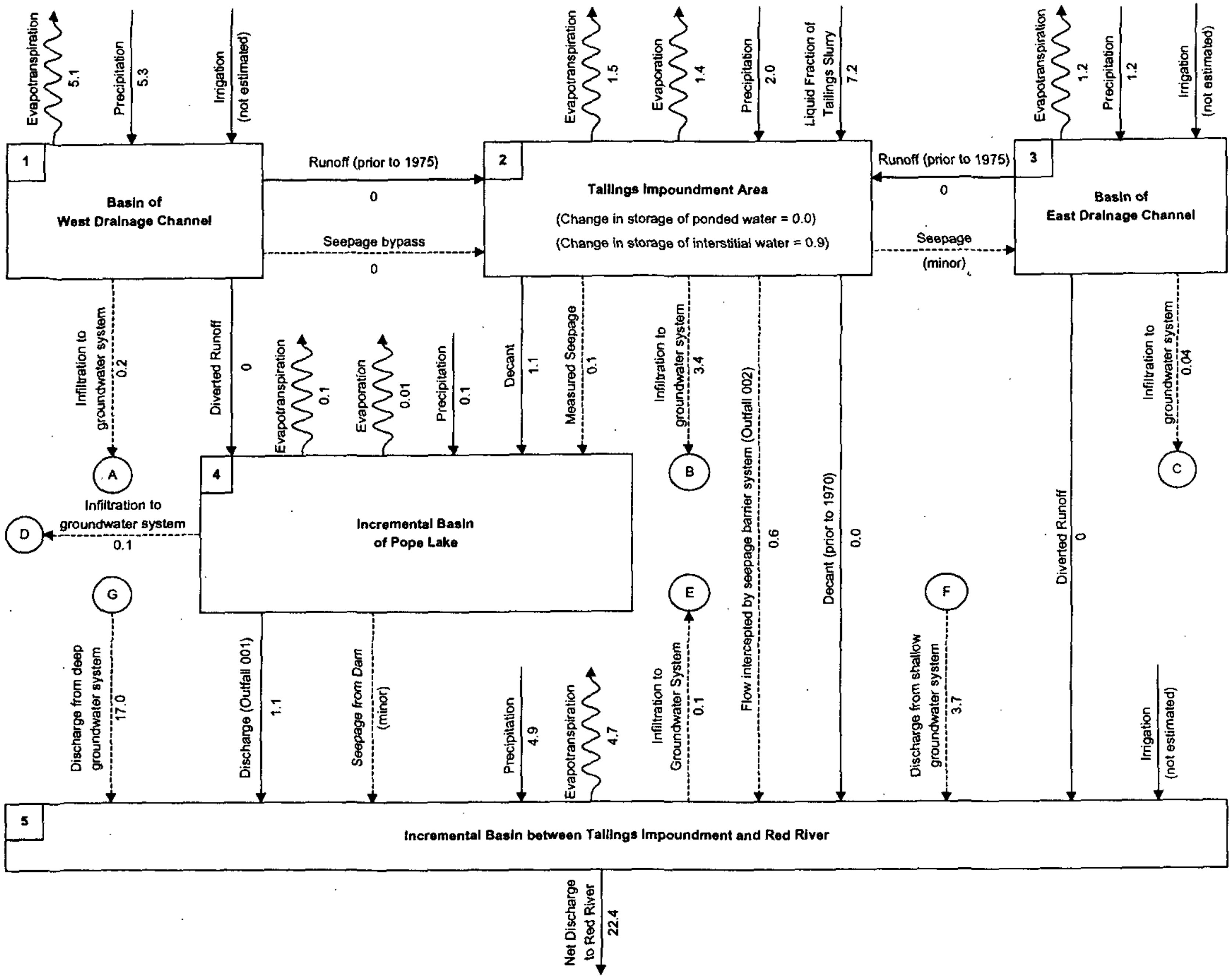
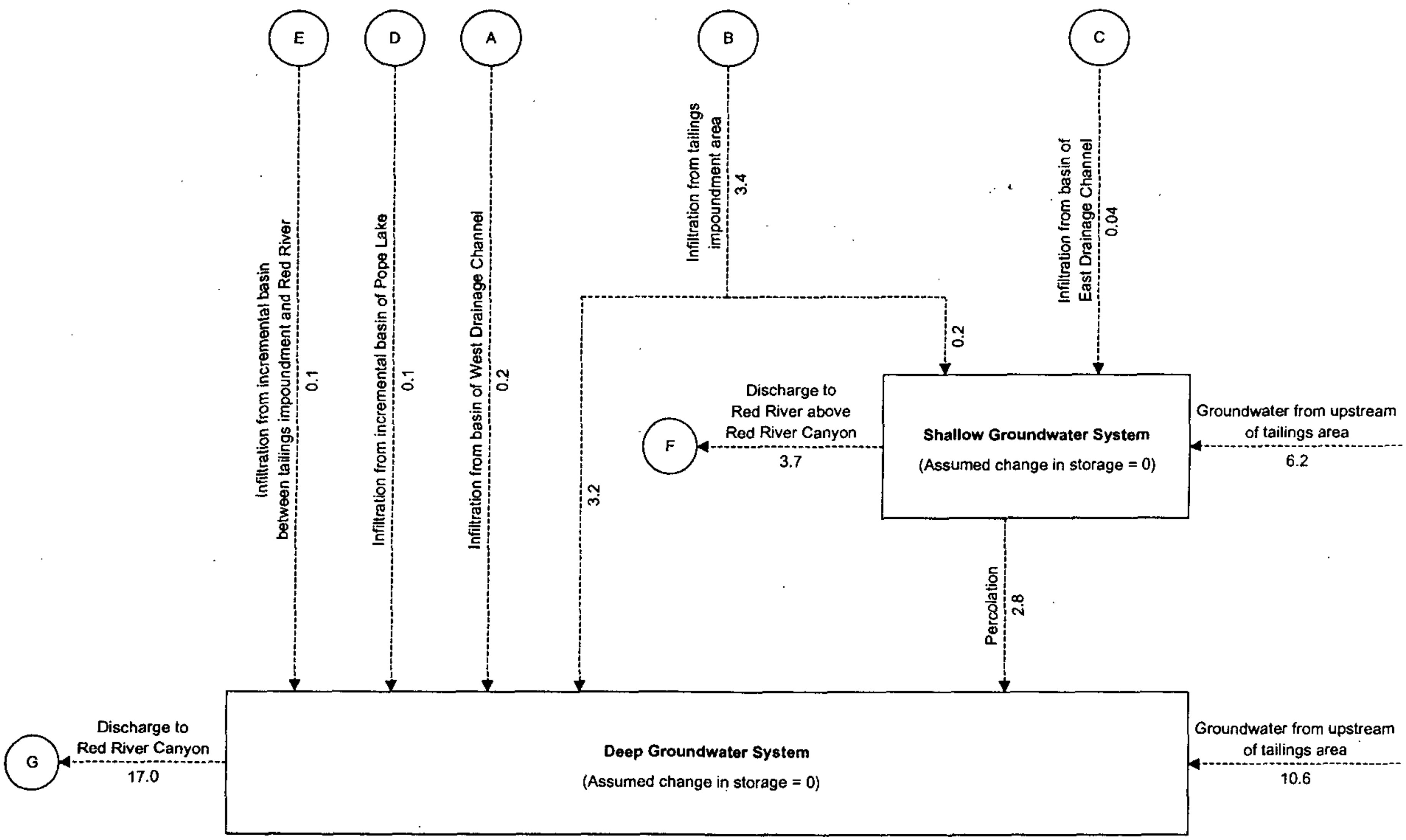
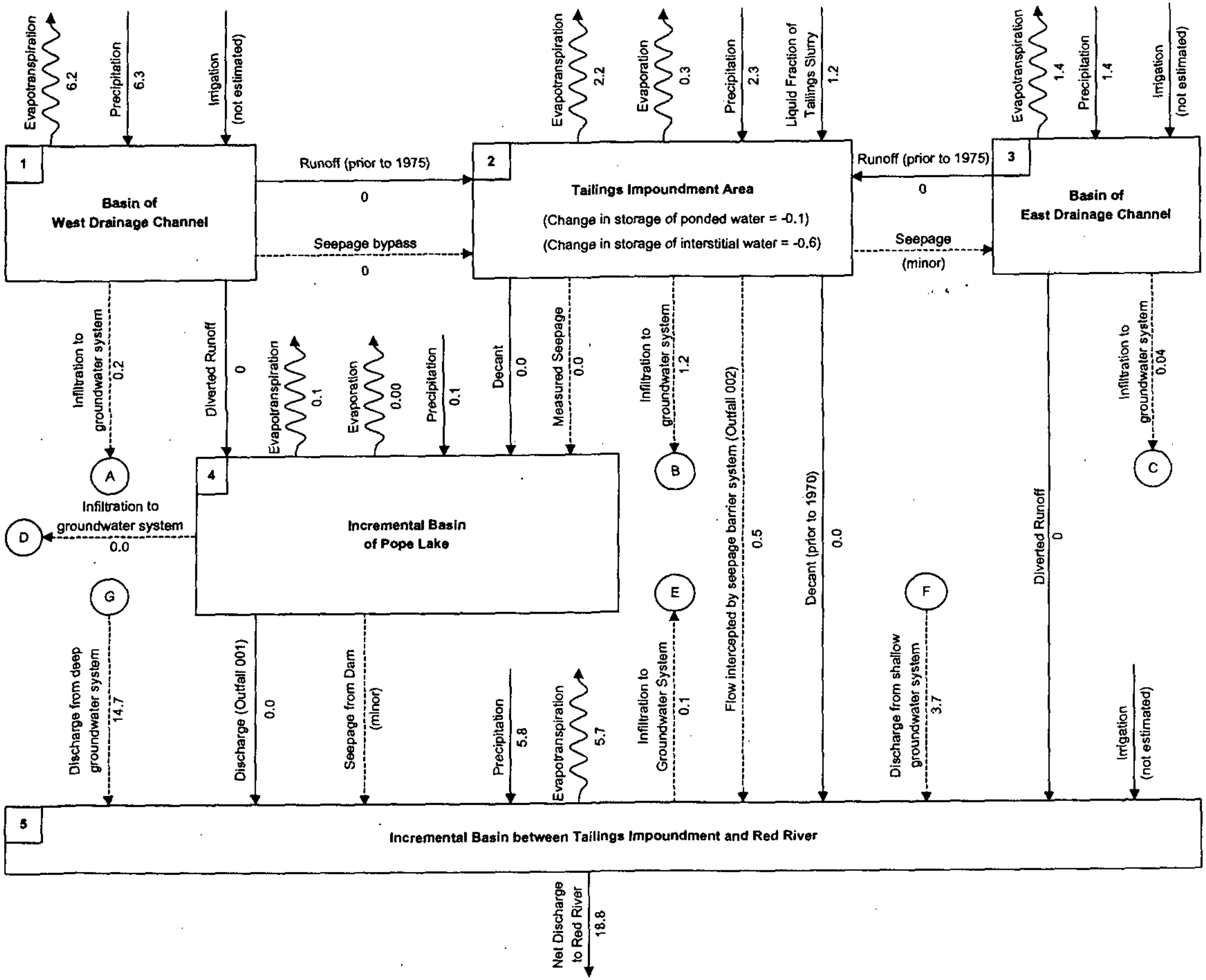


Figure 17a. Estimated Average Annual Water Balance for Period 1976 to 1985 (ft^3/s)



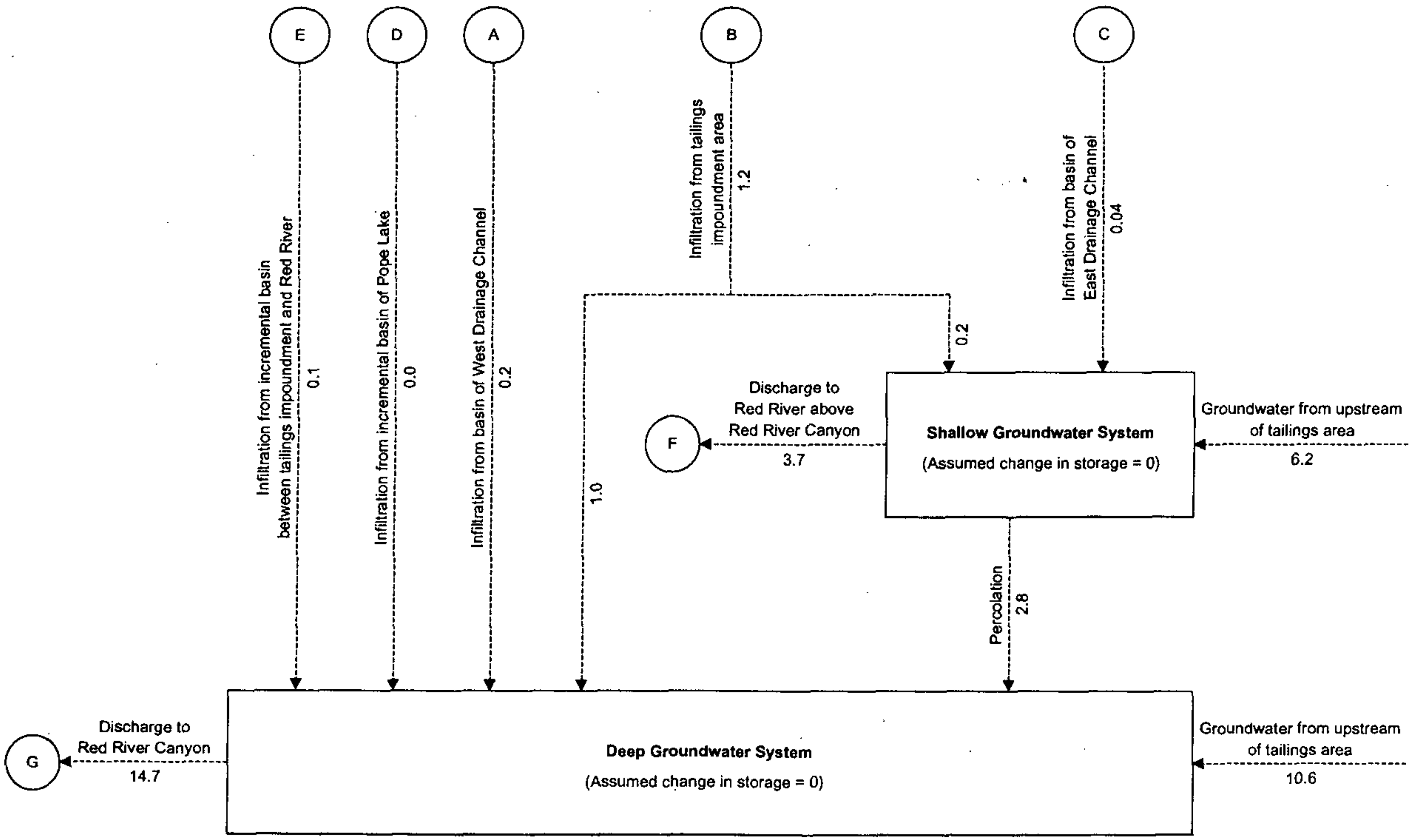
M-00001817

Figure 17b. Estimated Average Annual Water Balance for Period 1976 to 1985 (ft^3/s)



M-00001818

Figure 18a. Estimated Average Annual Water Balance for Period 1992 to 1996 (ft^3/s)



M-00001819

Figure 18b. Estimated Average Annual Water Balance for Period 1992 to 1996 (ft^3/s)

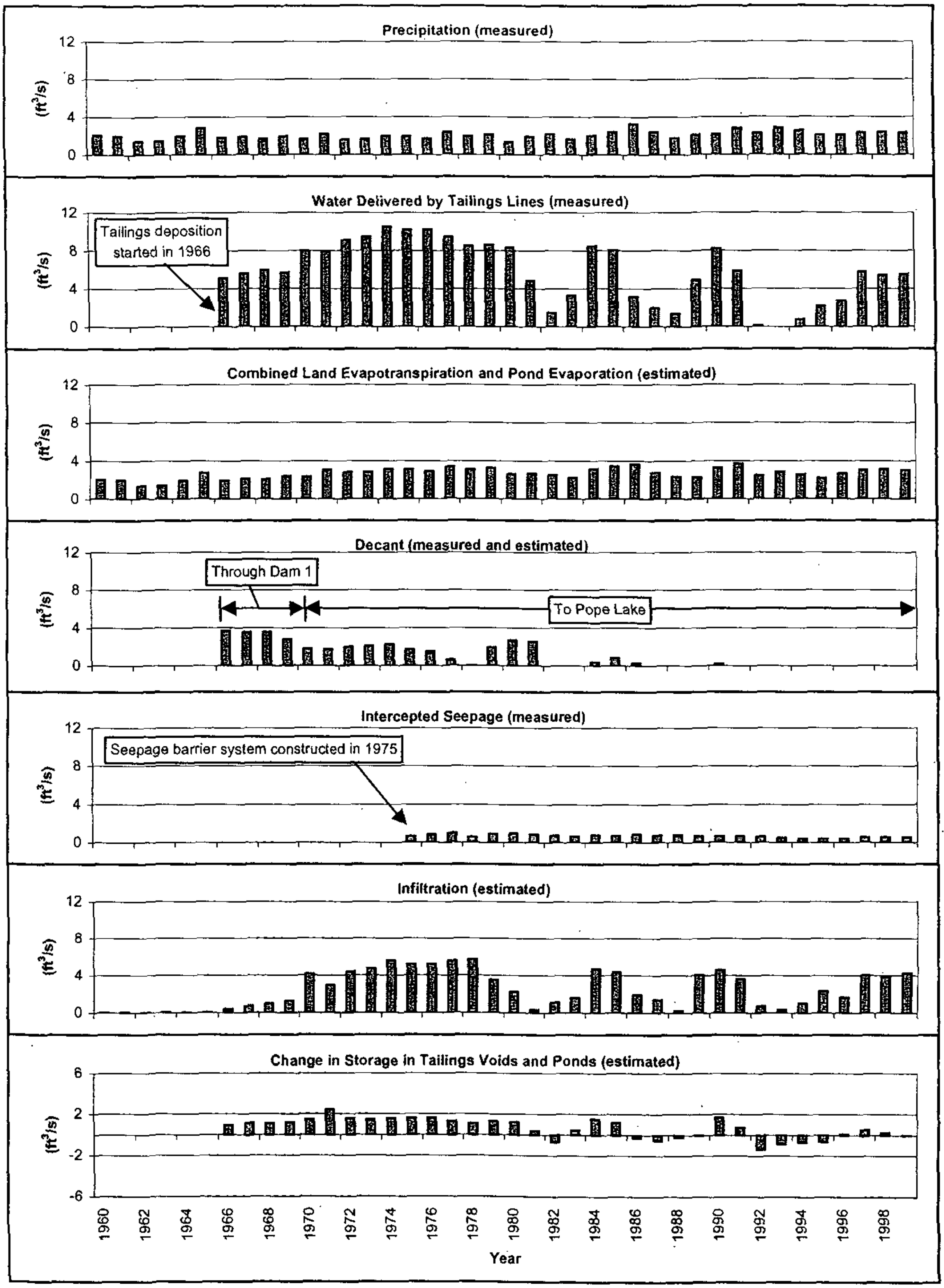
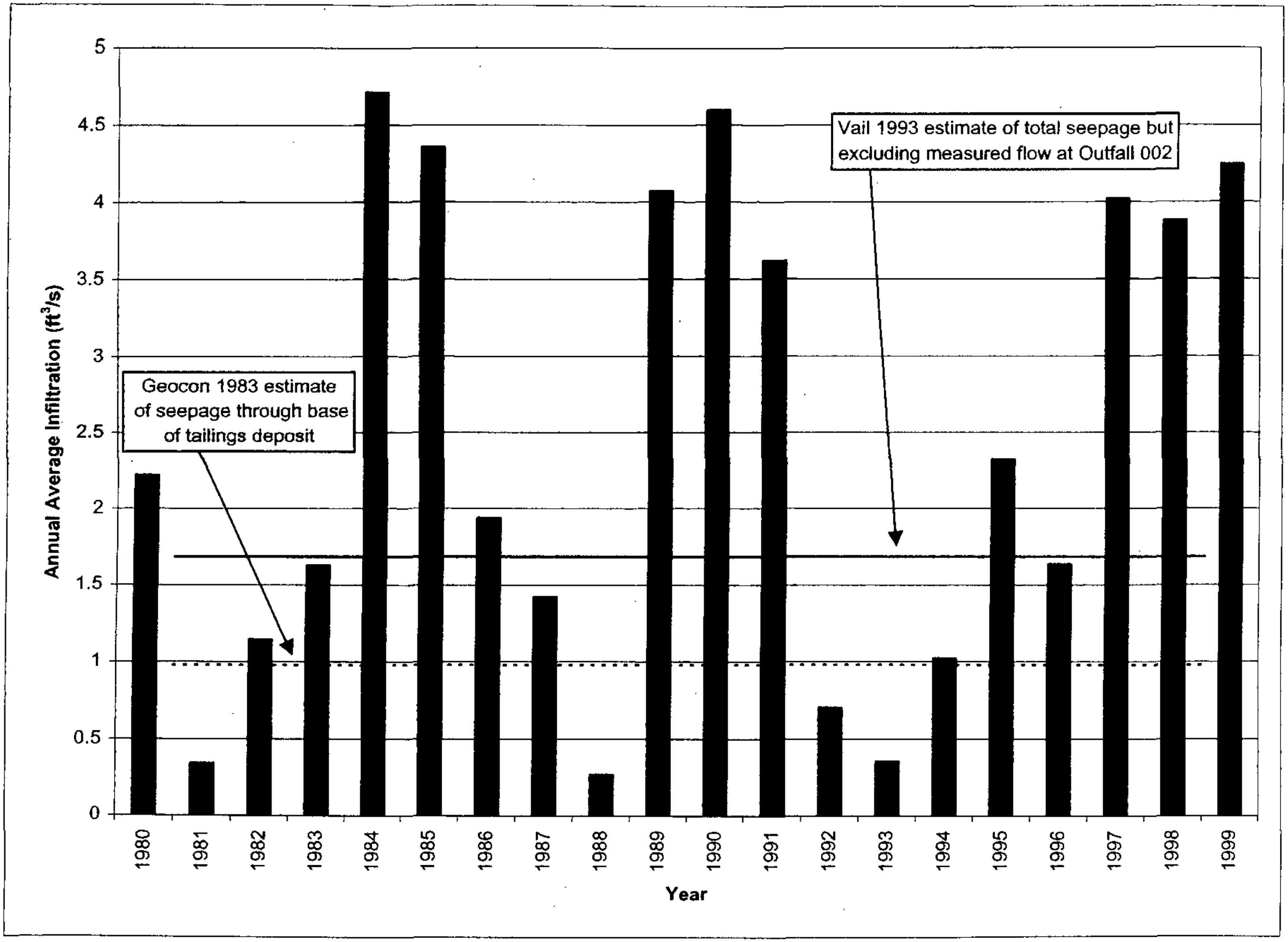


Figure 19. Annual Water Balance Components for Subbasin 2



M-00001821

Figure 20. Reconstructed Record of Infiltration in Subbasin 2 for Period 1980 to 1999

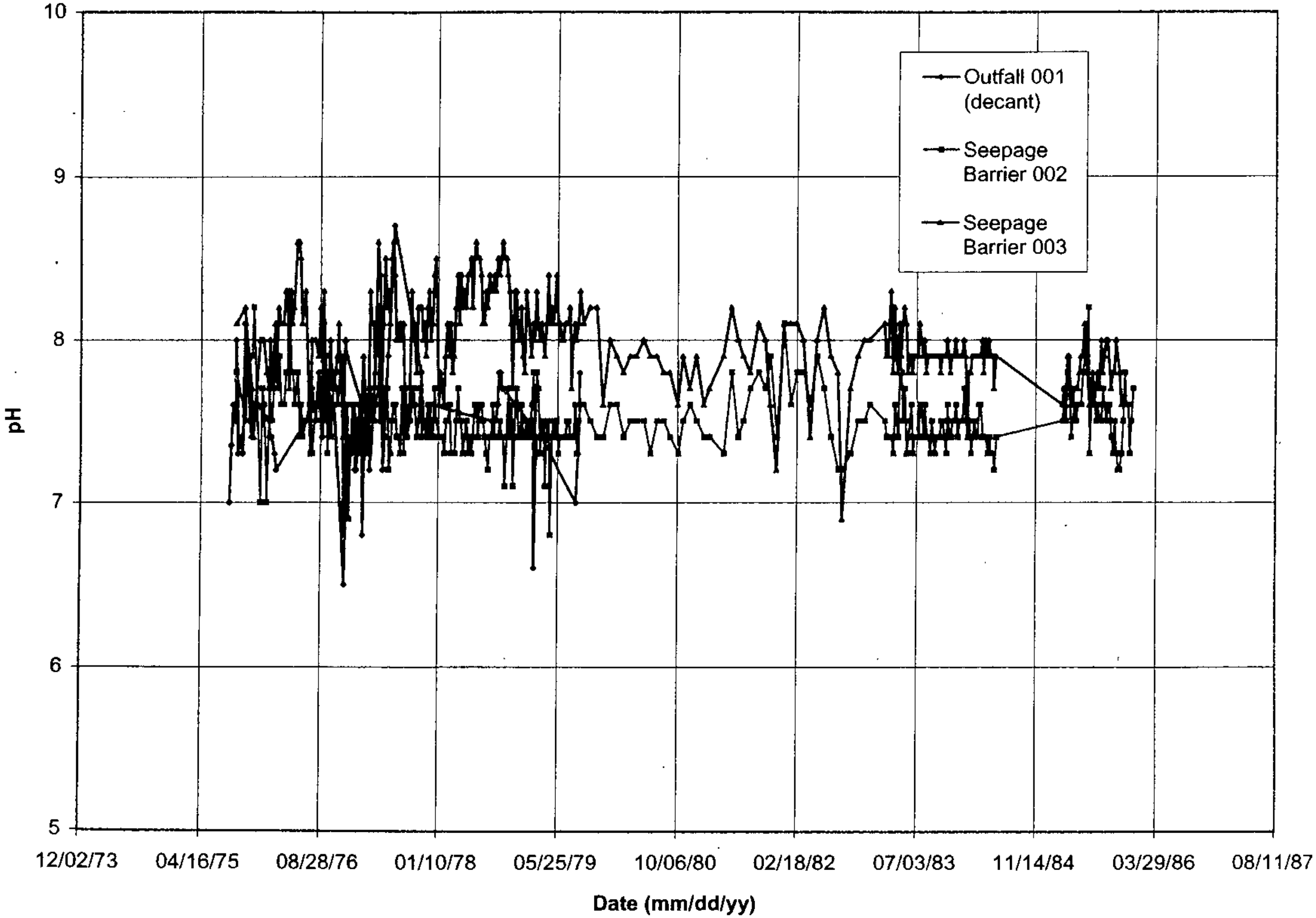


Figure 21a. pH in decant water and seepage for Questa Tailings Facility (1975-1985).

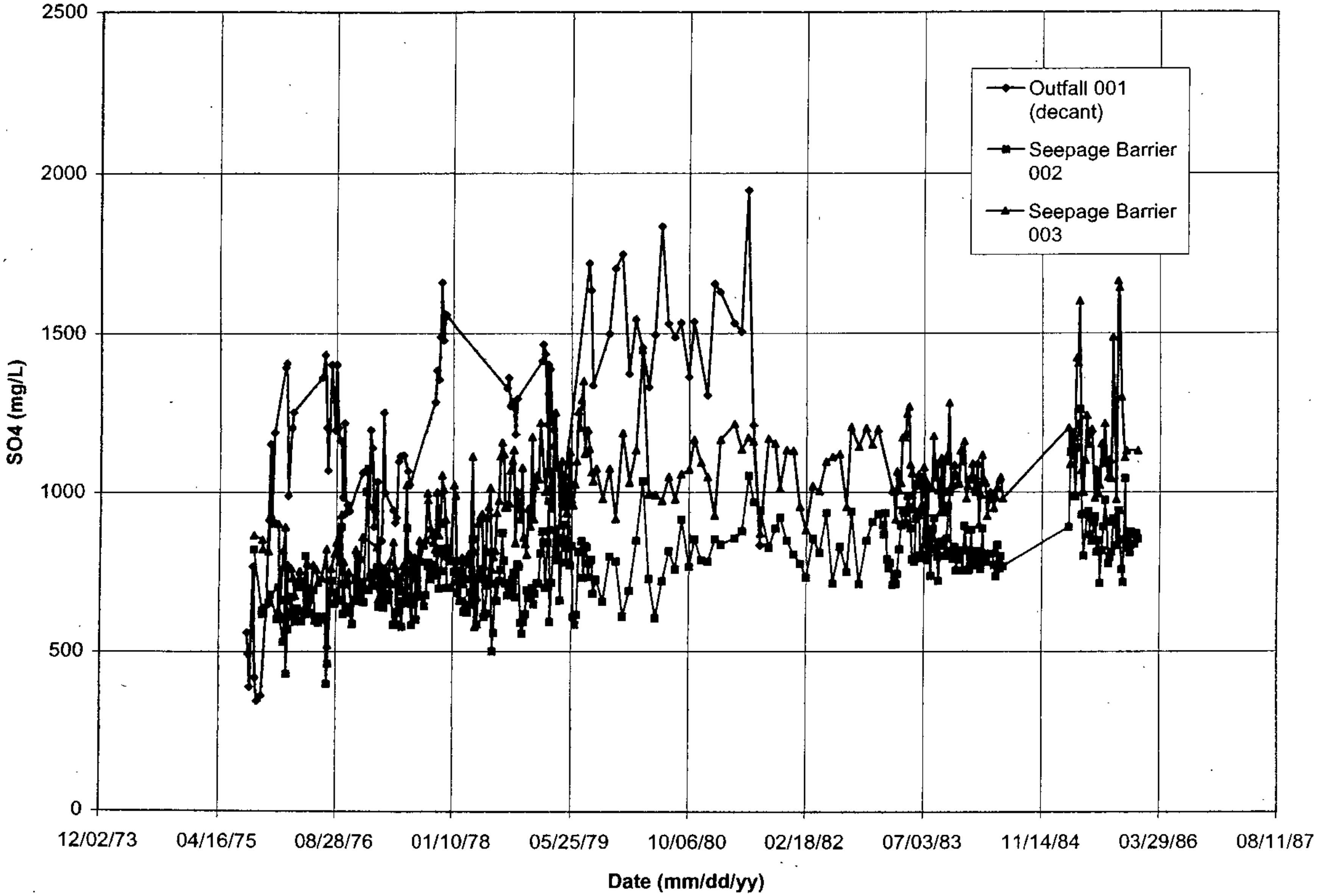
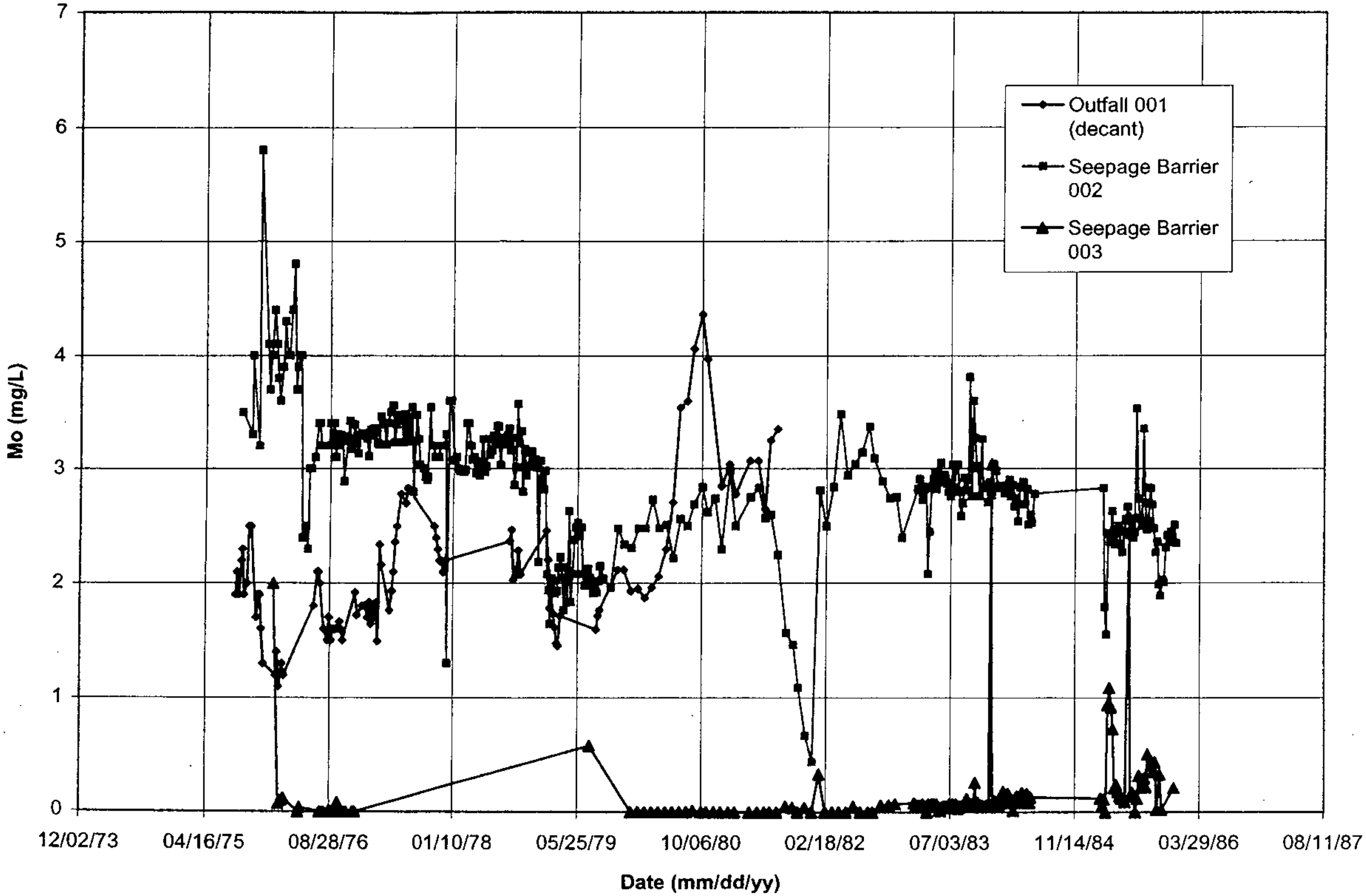


Figure 21b. Sulphate in decant water and seepage from Questa Tailings Facility (1975-1985).

M-00001823



M-00001824

Figure 21c. Molybdenum in decant water and seepage from Questa Tailings Facility (1975-1985).

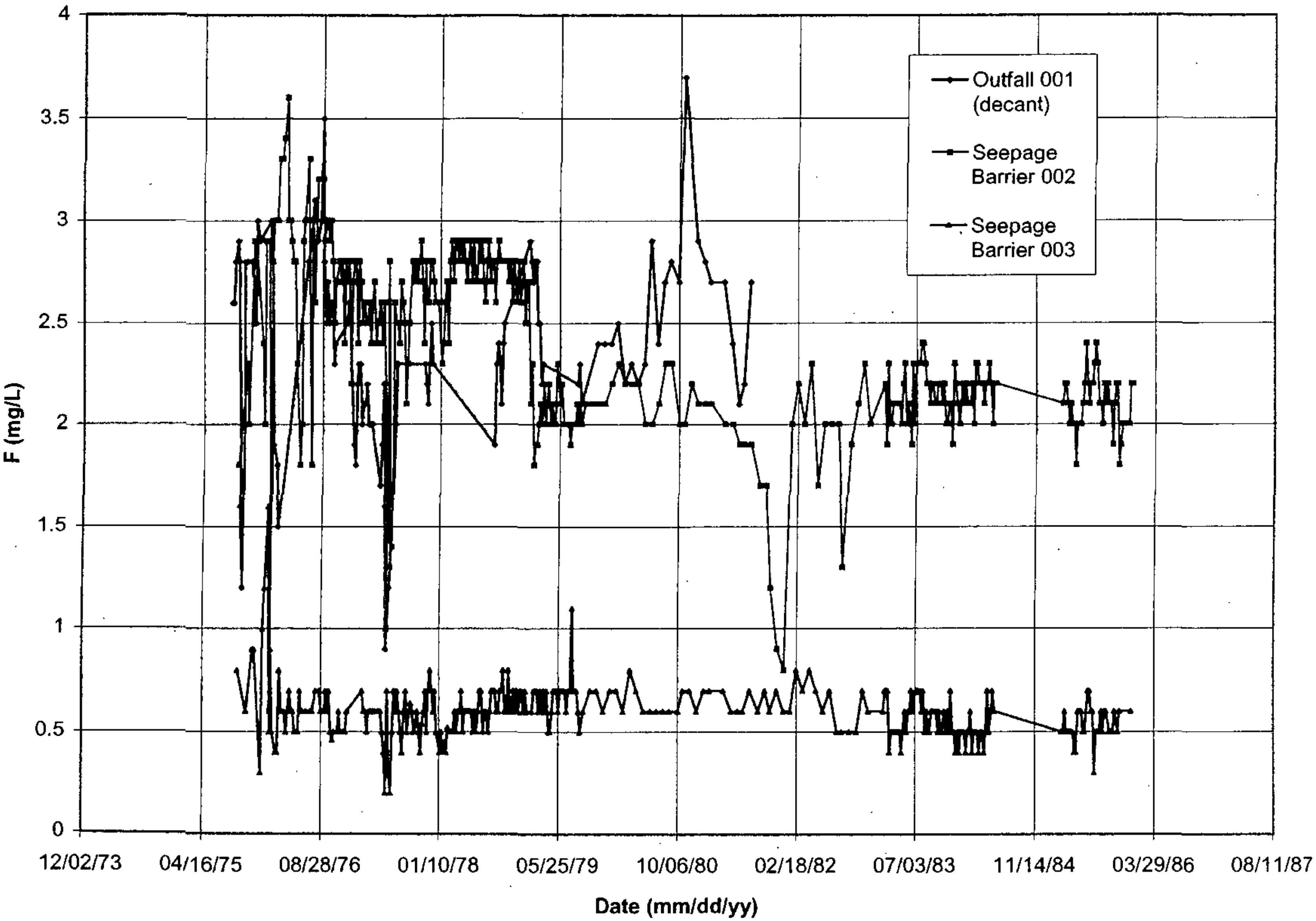
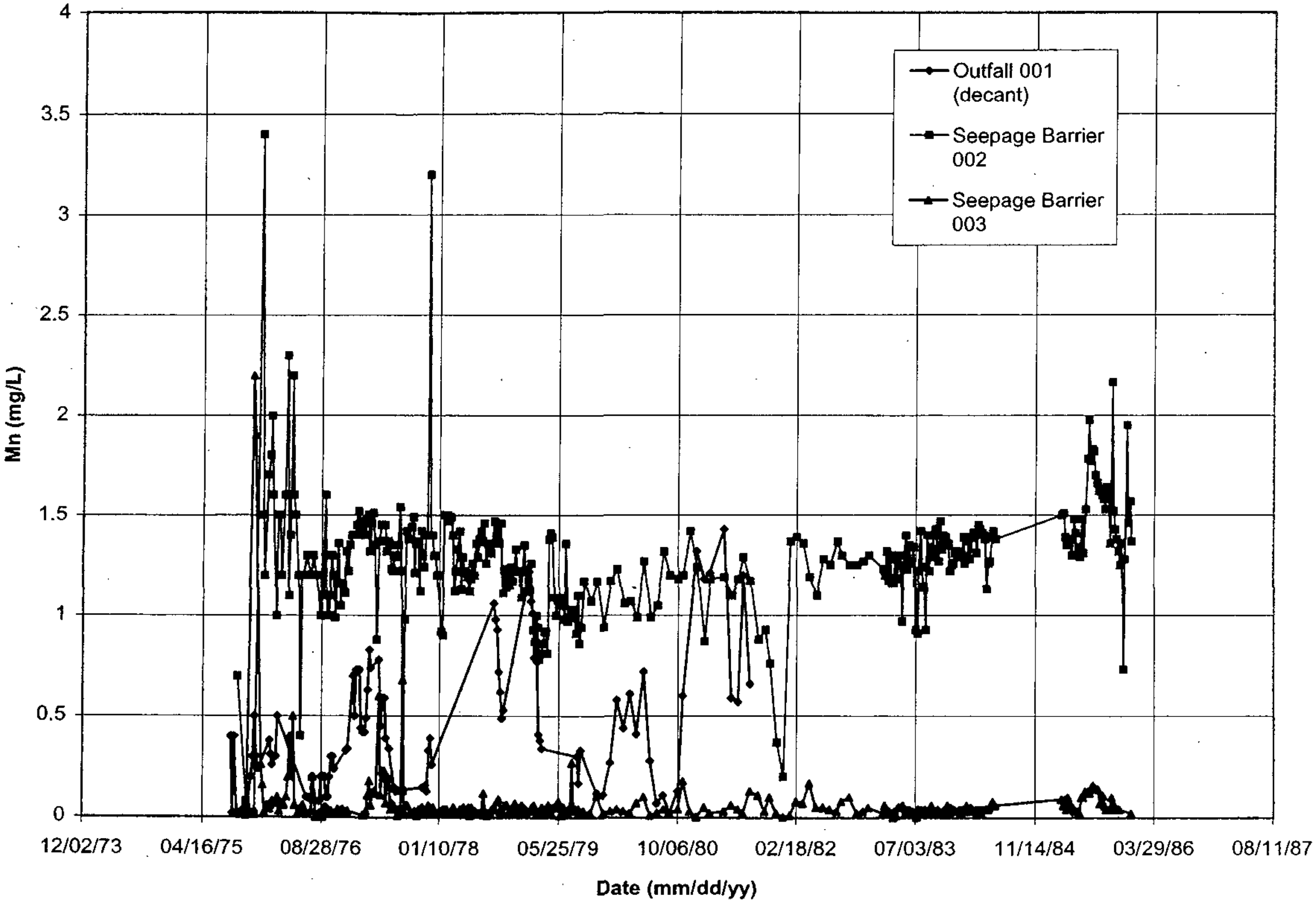


Figure 21d. Fluoride in decant water and seepage for Questa Tailings Facility (1975-1985).

M-00001825



M-00001826

Figure 21e. Manganese in decant water and seepage for Questa Tailings Facility (1975-1985).

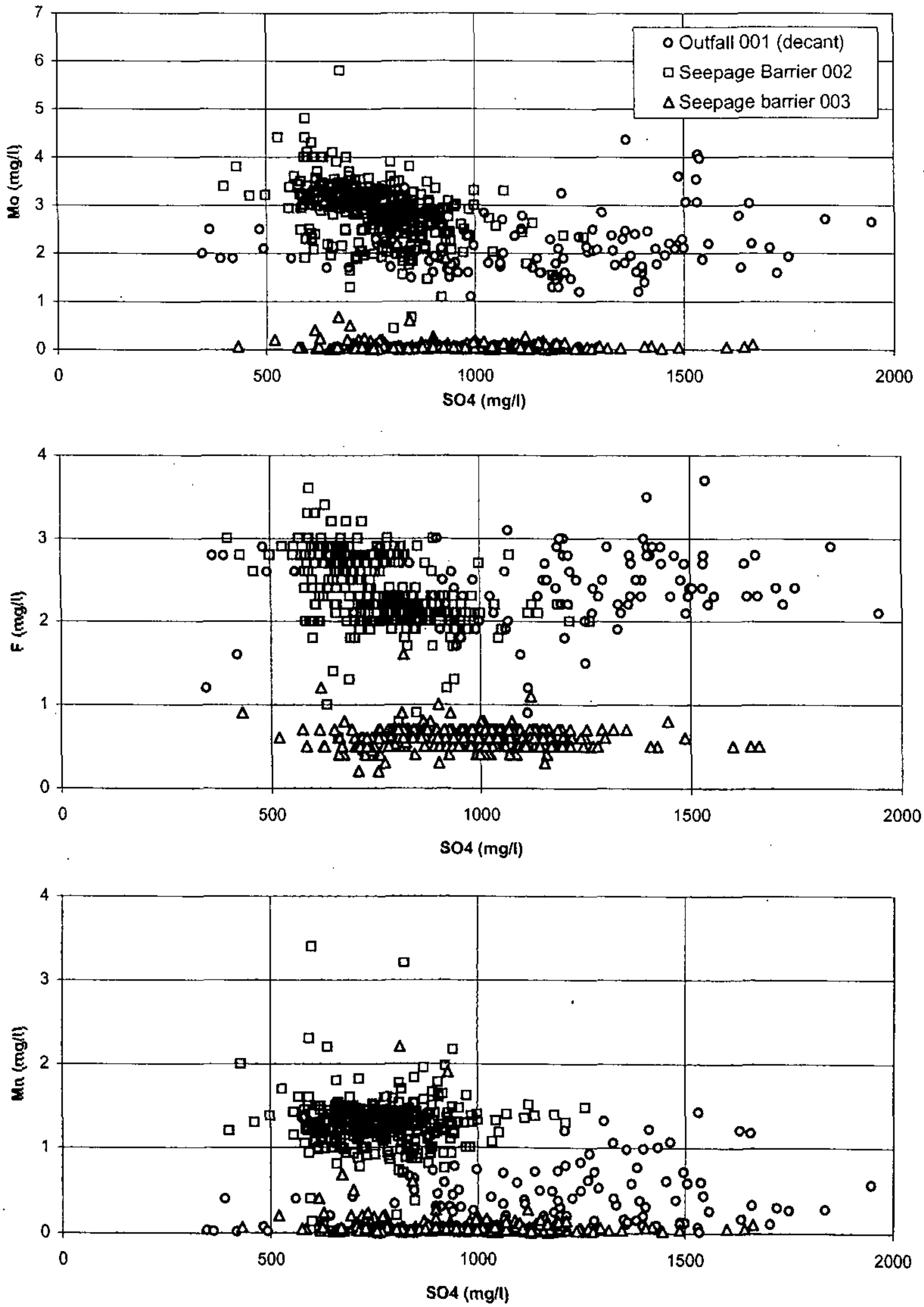
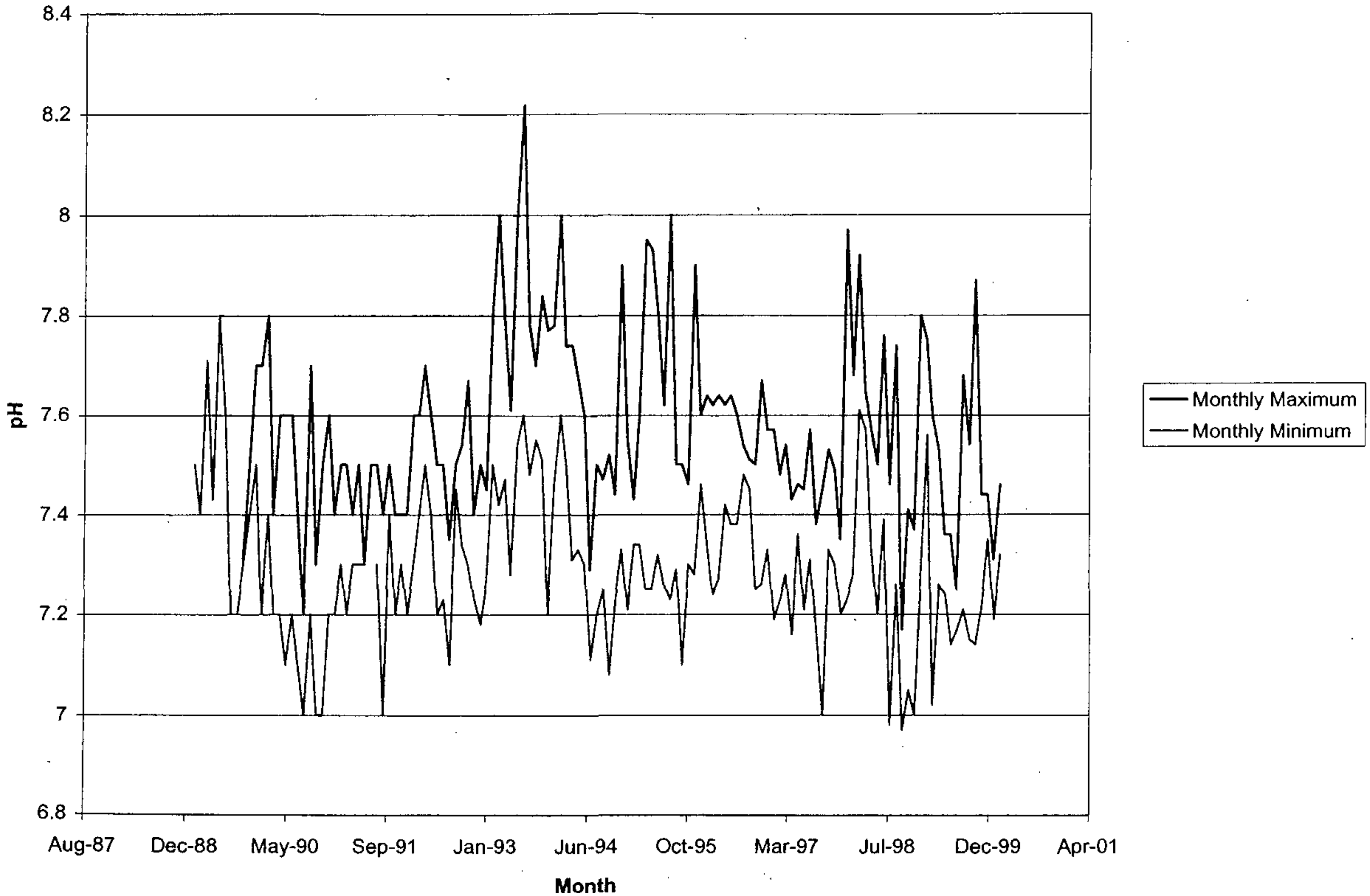


Figure 22. Scatter plots of Mo, Mn, and F versus SO4.



M-00001828

Figure 23a. pH in Outfall 002 (1988-1999).

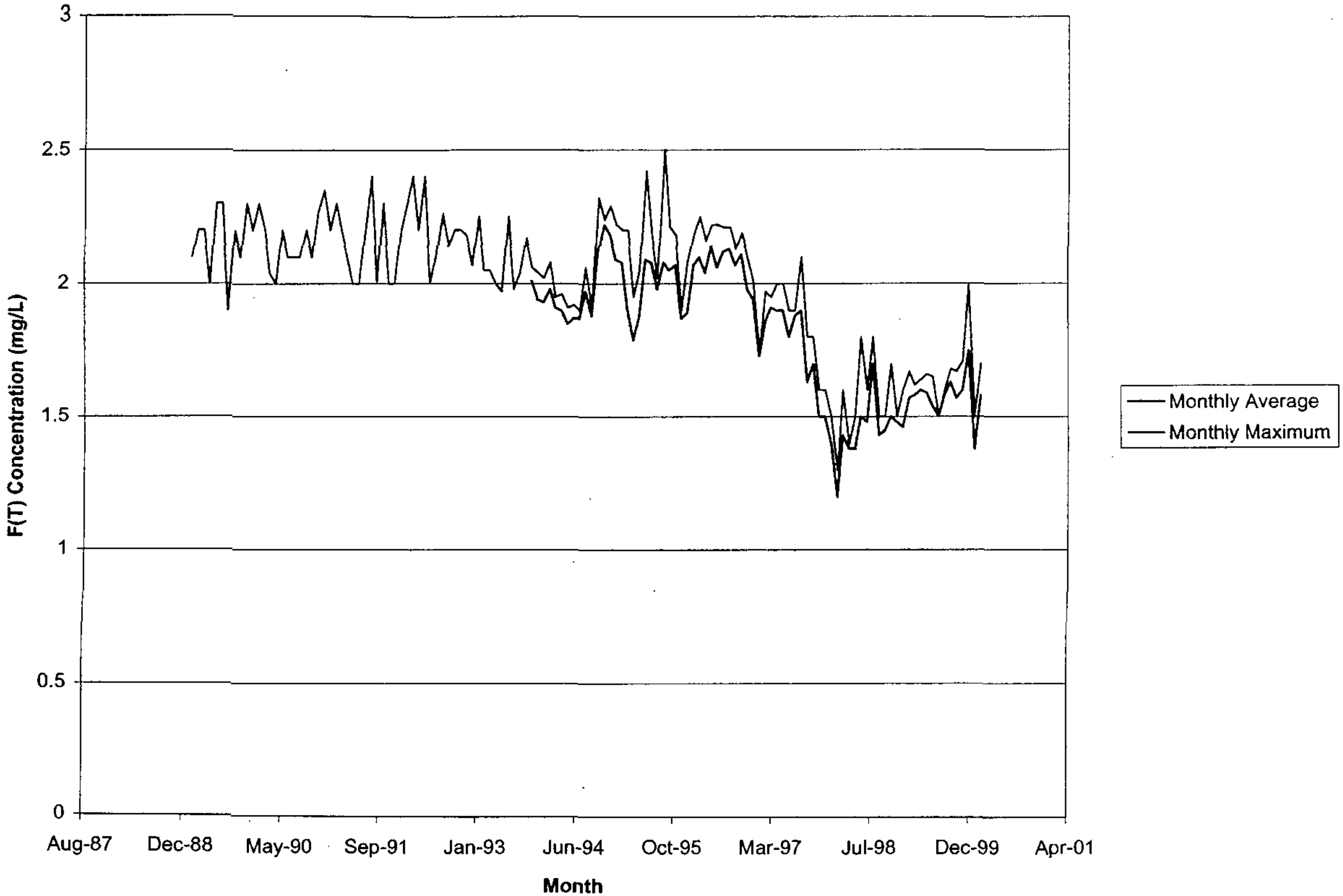


Figure 23b. Total Fluoride concentration in Outfall 002 (1988-1999).

M-0001829

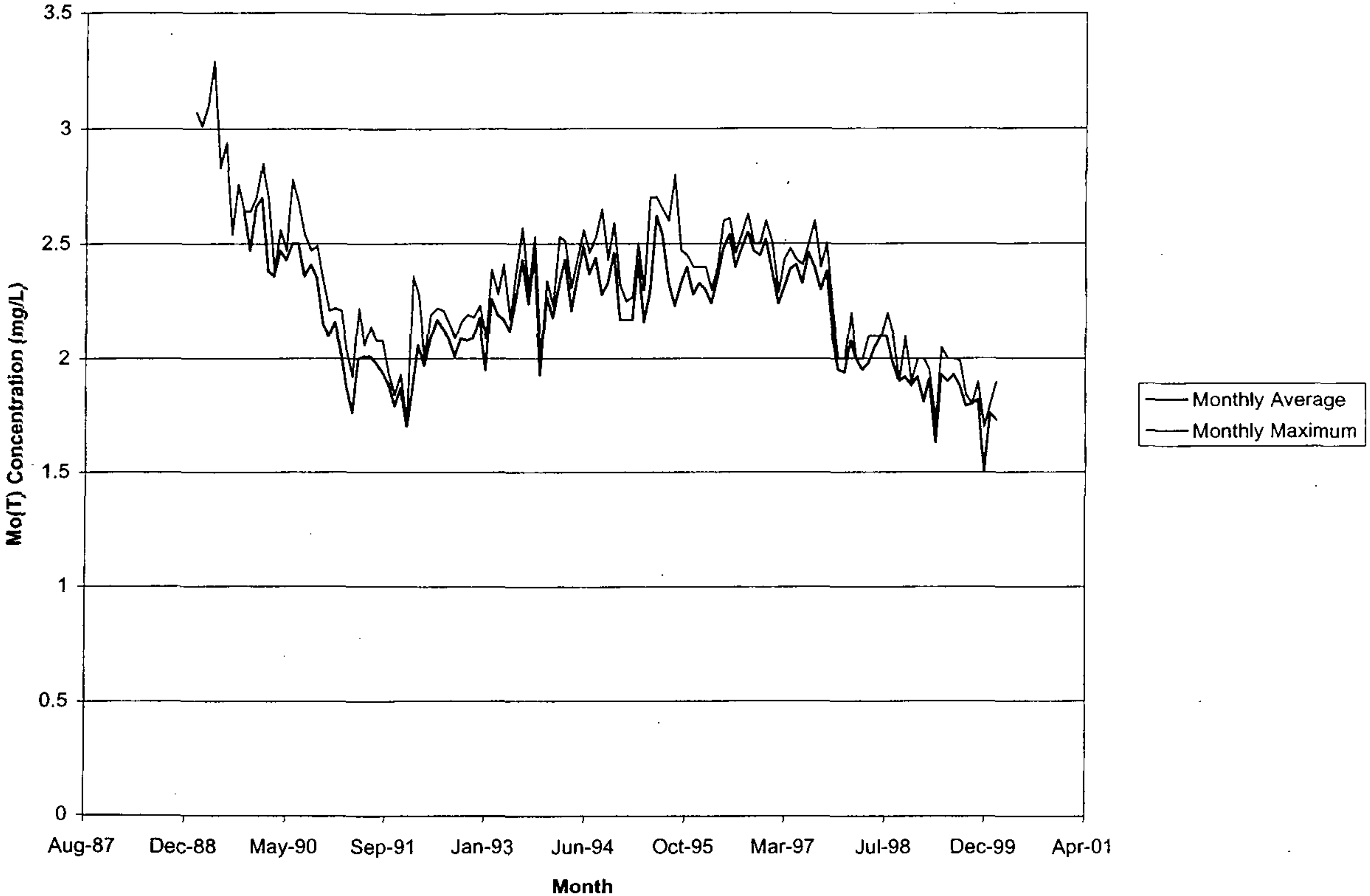


Figure 23c. Total molybdenum concentrations in Outfall 002 (1988-1999).

M-00001830

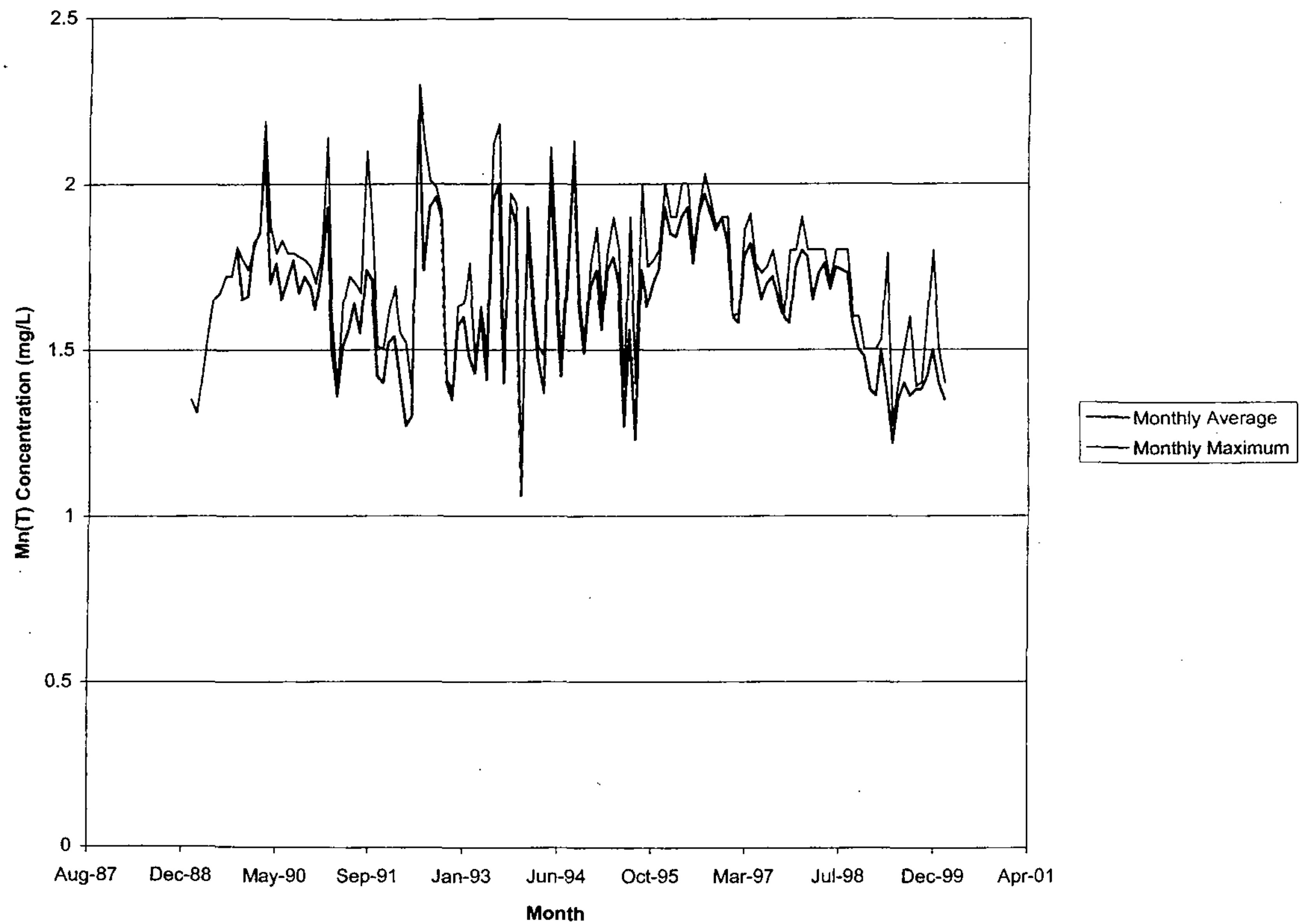
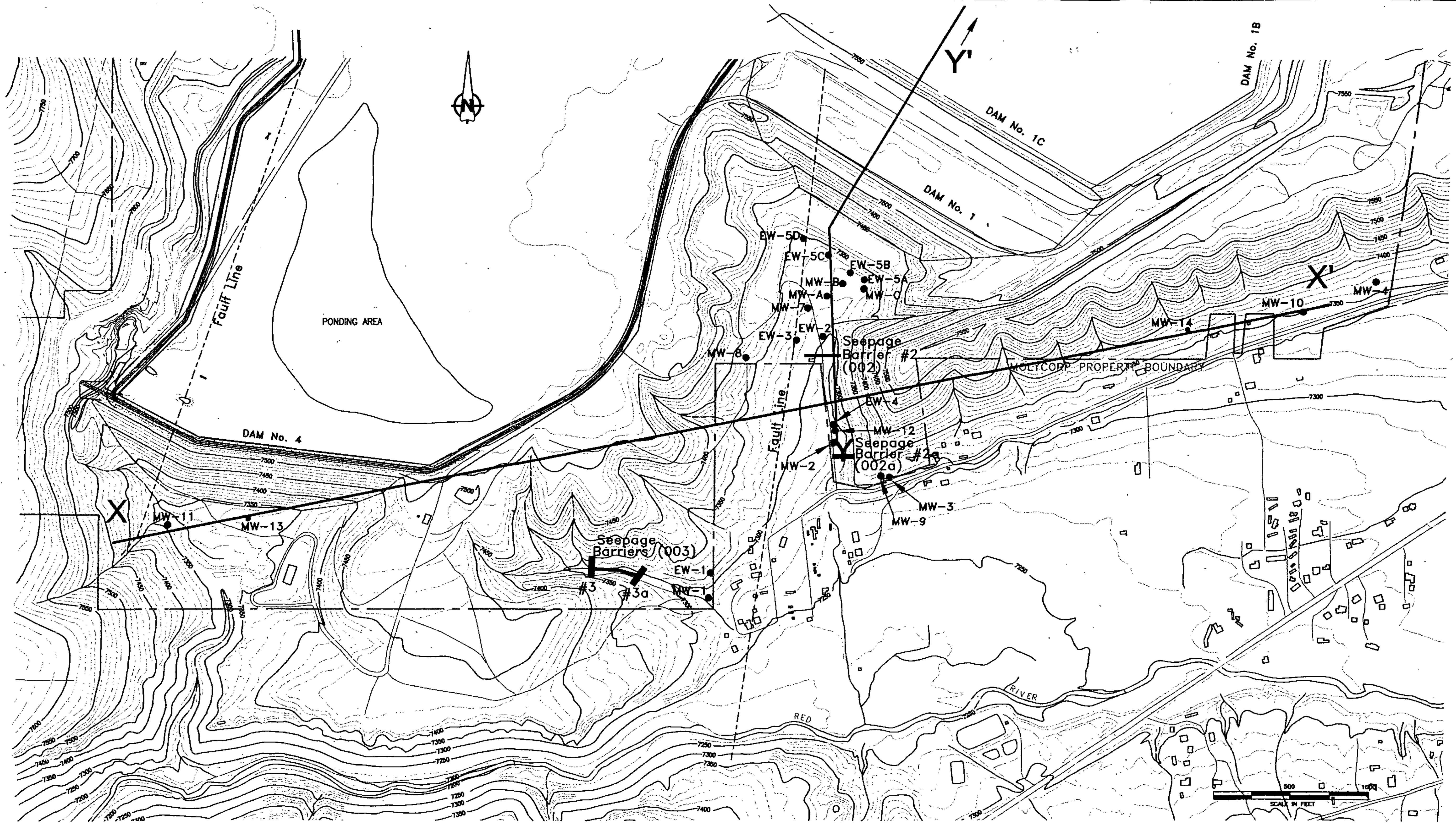


Figure 23d. Total manganese concentrations in Outfall 002 (1988-1999).

M-00001831



CLIENT:	MOLYCORP, INC.
PROJECT No:	052010
PROJECT:	WATER AND LOAD BALANCE STUDY
LOCATION:	QUESTA TAILINGS FACILITY NEW MEXICO, USA

ROBERTSON GEOCONSULTANTS INC.
Consulting Geotechnical and Environmental Engineers

Groundwater Monitoring Wells

DATE:	DRAWN BY:	FIGURE:
June 2000	JG	24

M-0001832

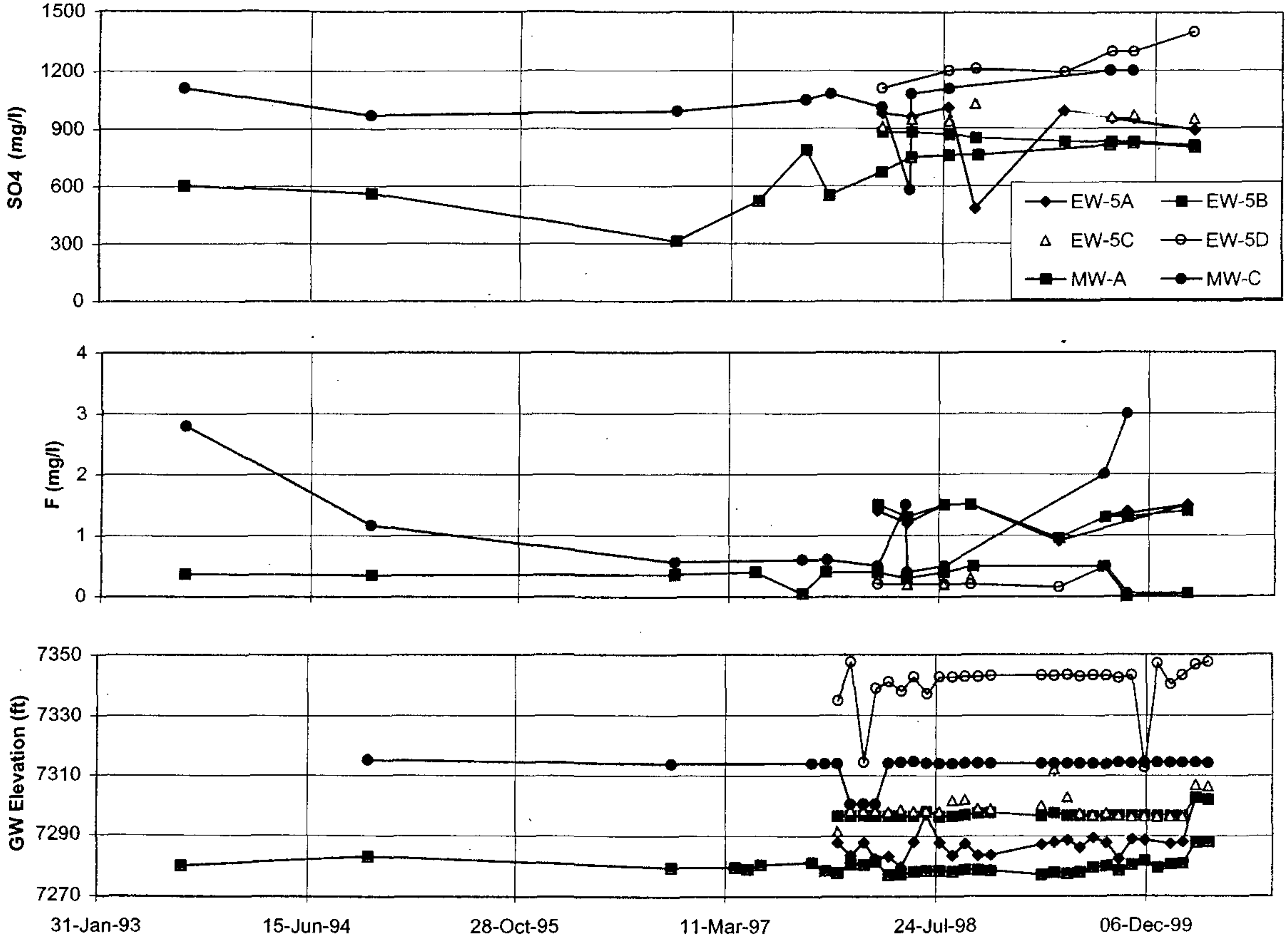
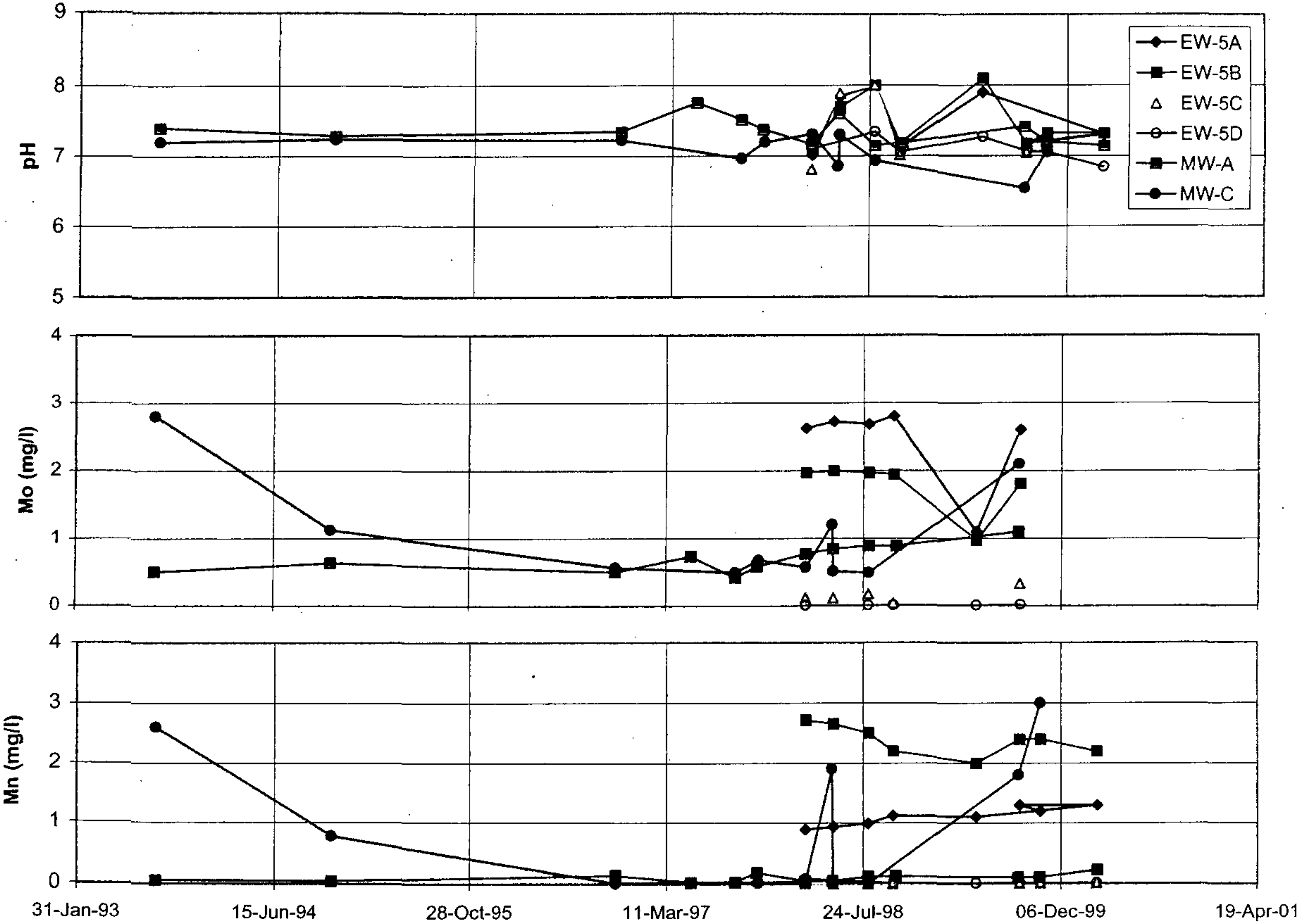


Figure 25a. SO4, F and groundwater elevations in monitoring wells at toe of Dam 1.

M-00001833



M-00001834

Figure 25b. pH, Mo, and Mn in groundwater monitoring wells at toe of *Dam 1*.

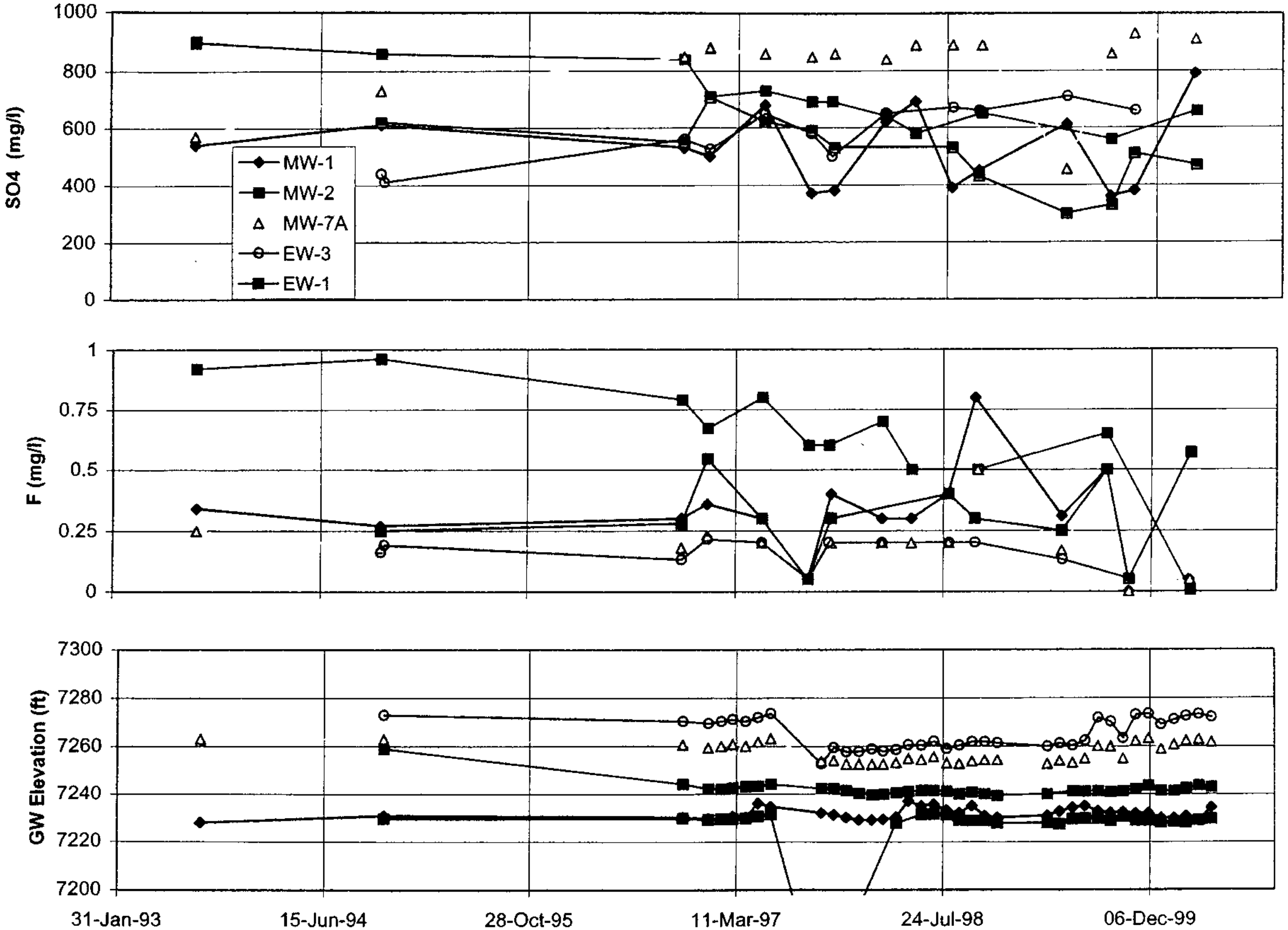
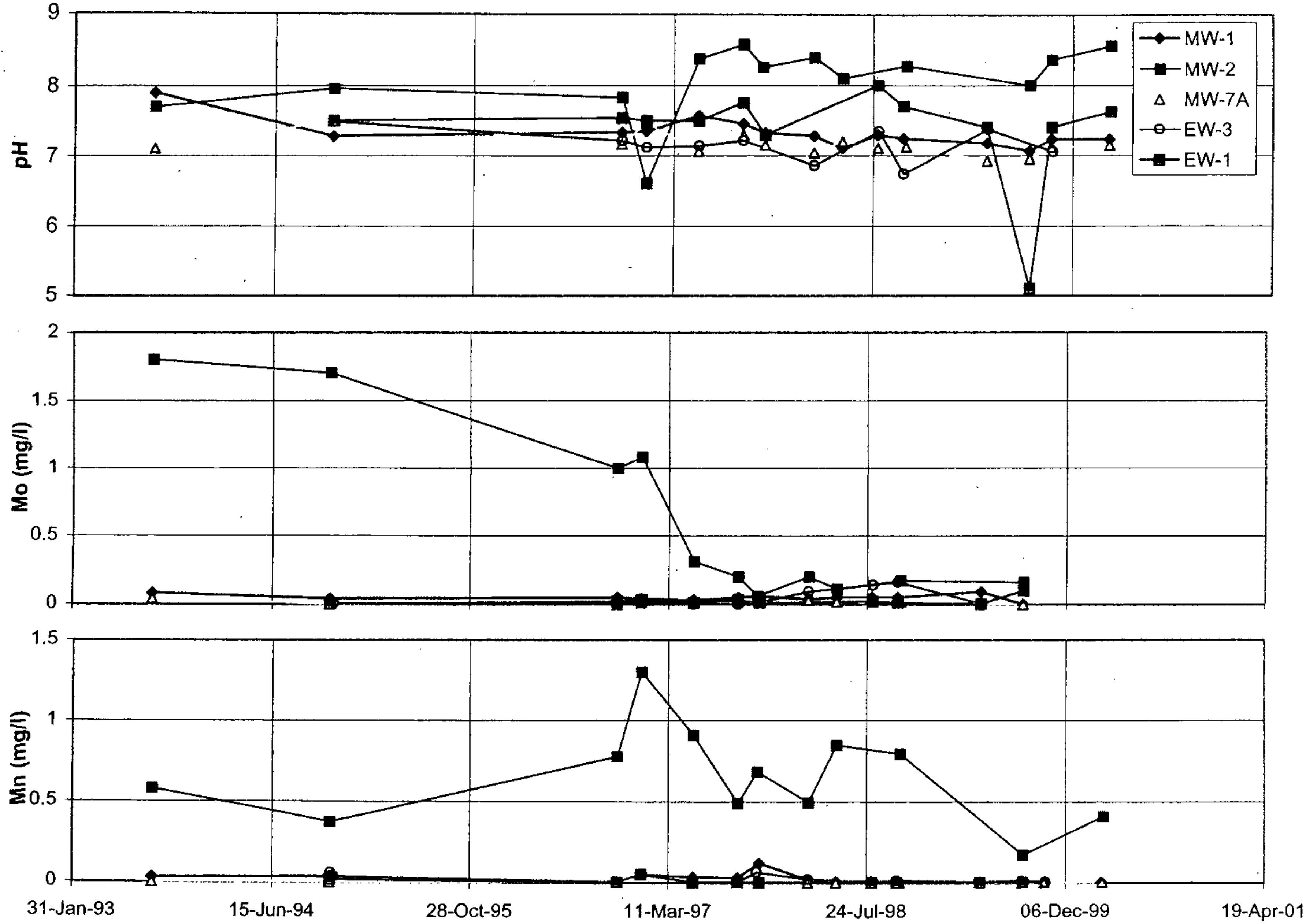


Figure 26a. SO4, F and groundwater elevations in monitoring wells downstream of Dam 1.

M-00001835



M-00001836

Figure 26b. pH, Mo, and Mn in groundwater monitoring wells downstream of Dam 1.

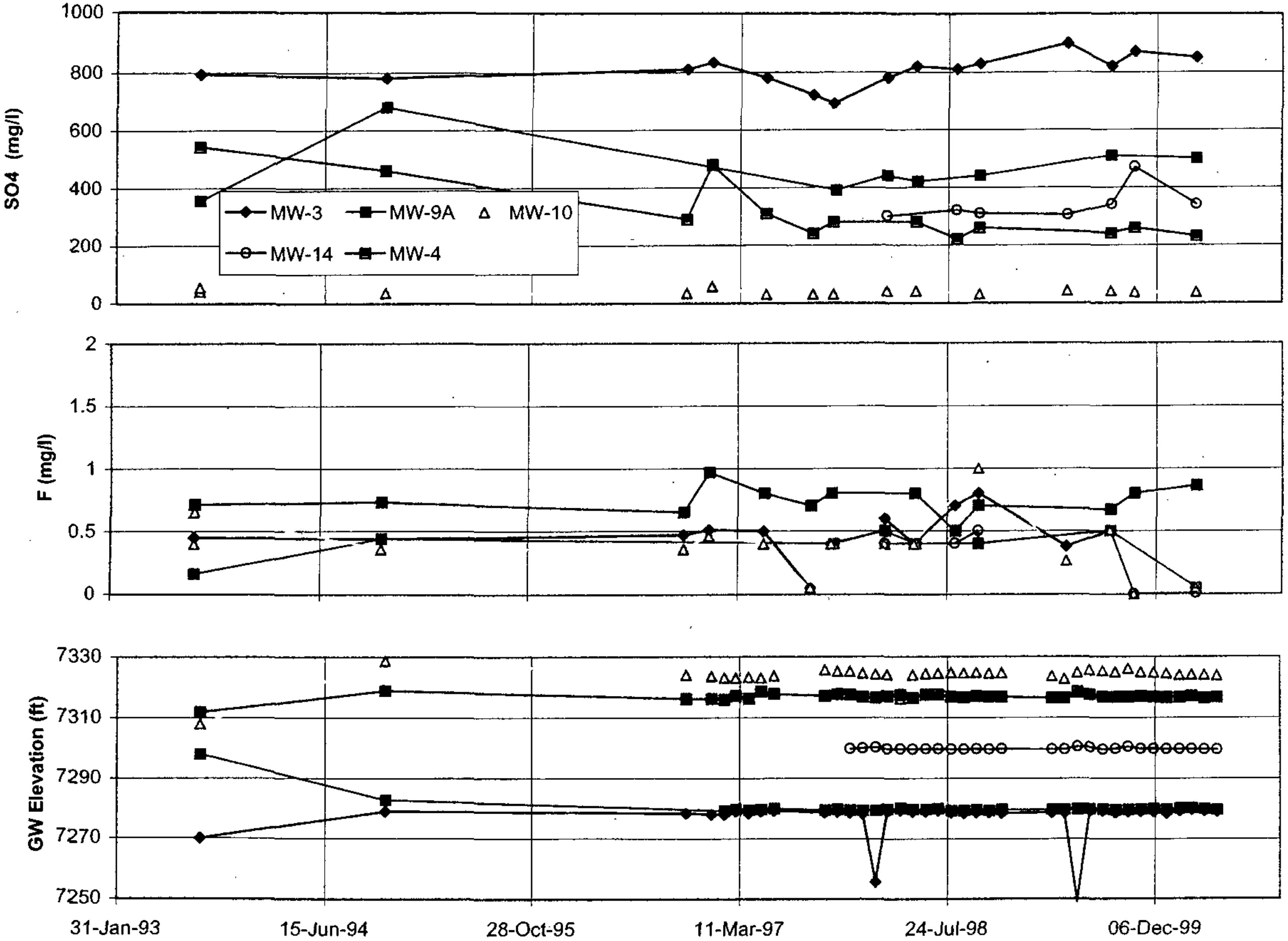
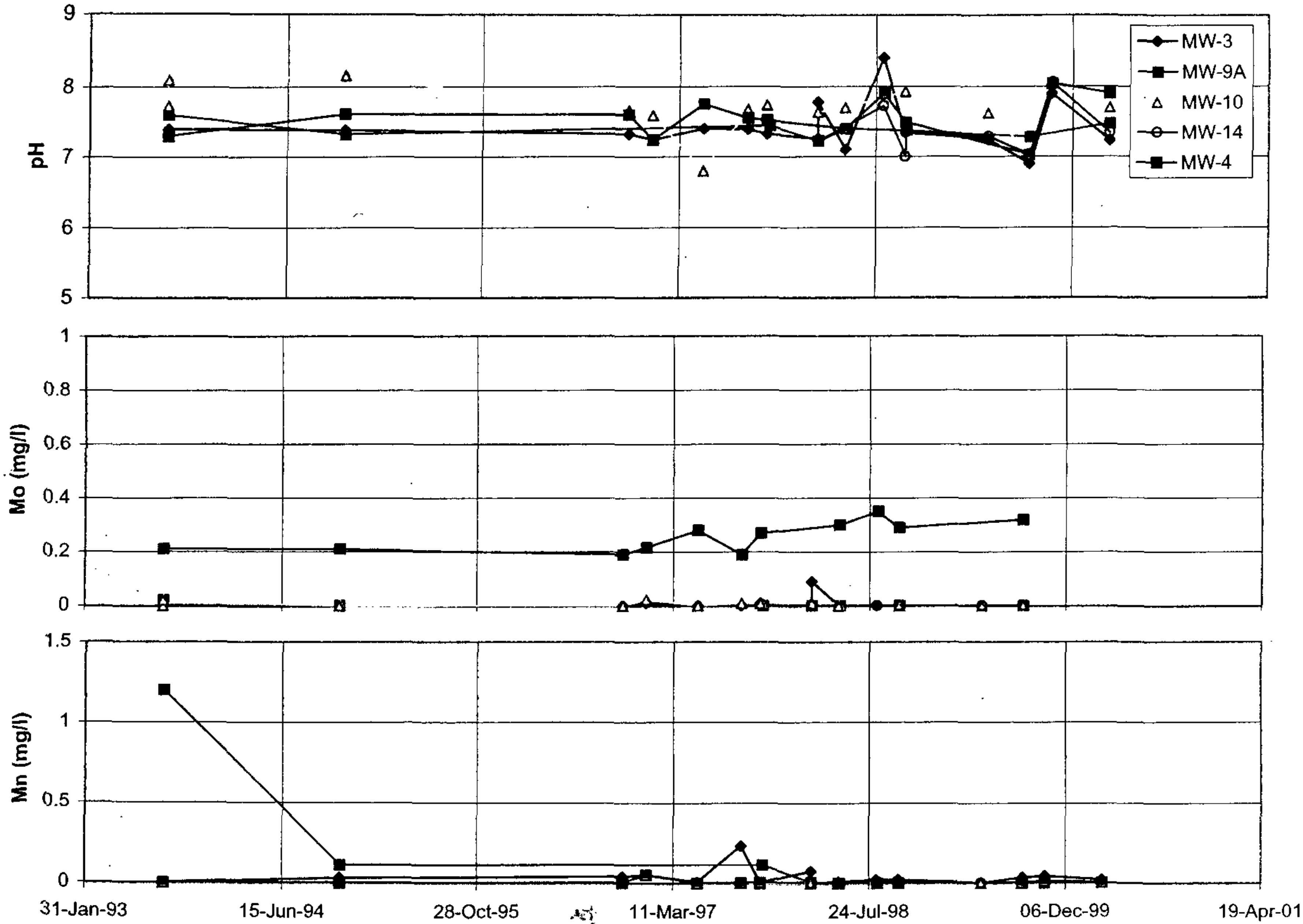


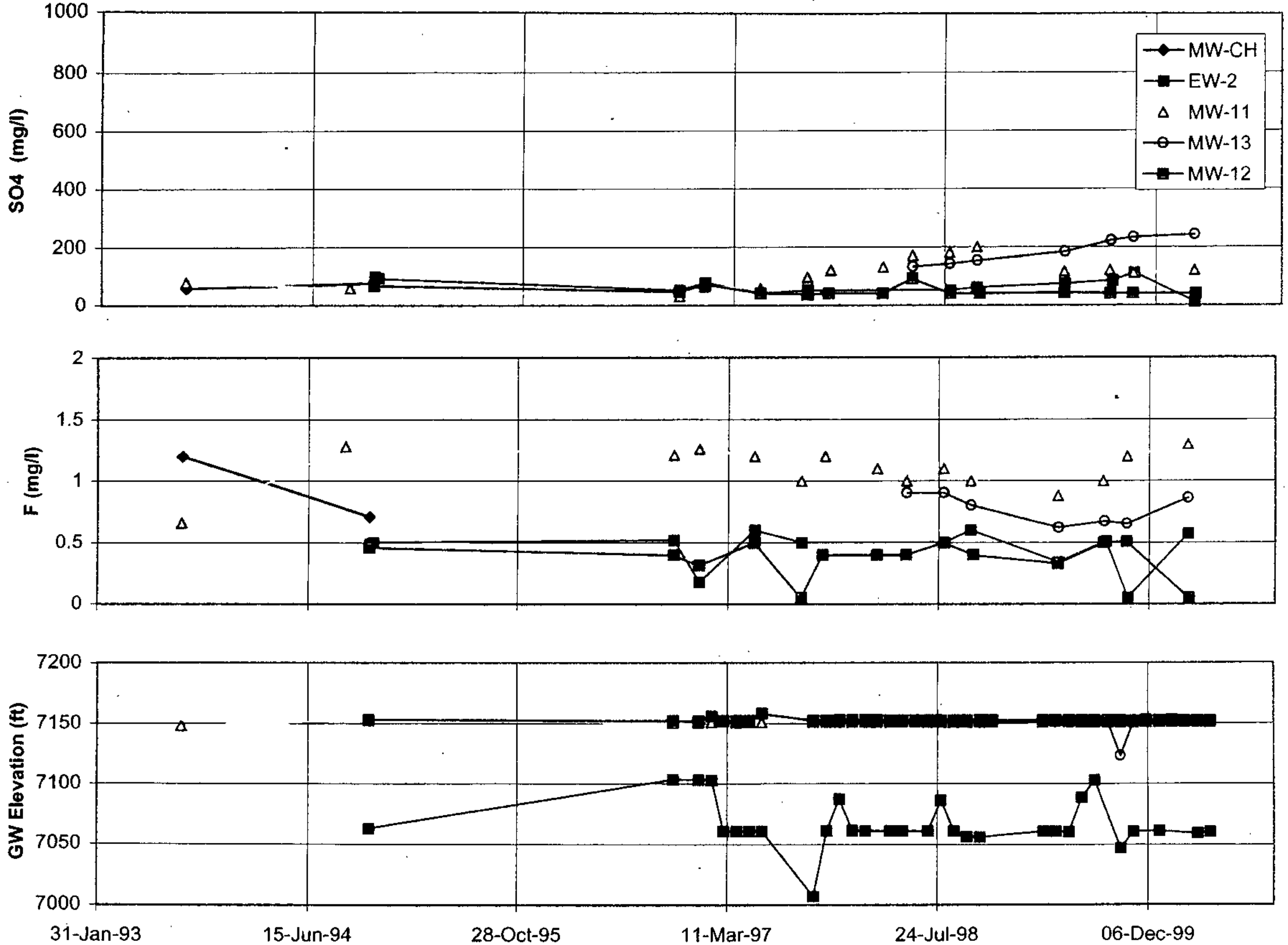
Figure 27a. SO4, F, and groundwater elevations in monitoring wells located east of Dam 1 arroyo.

M-00001837



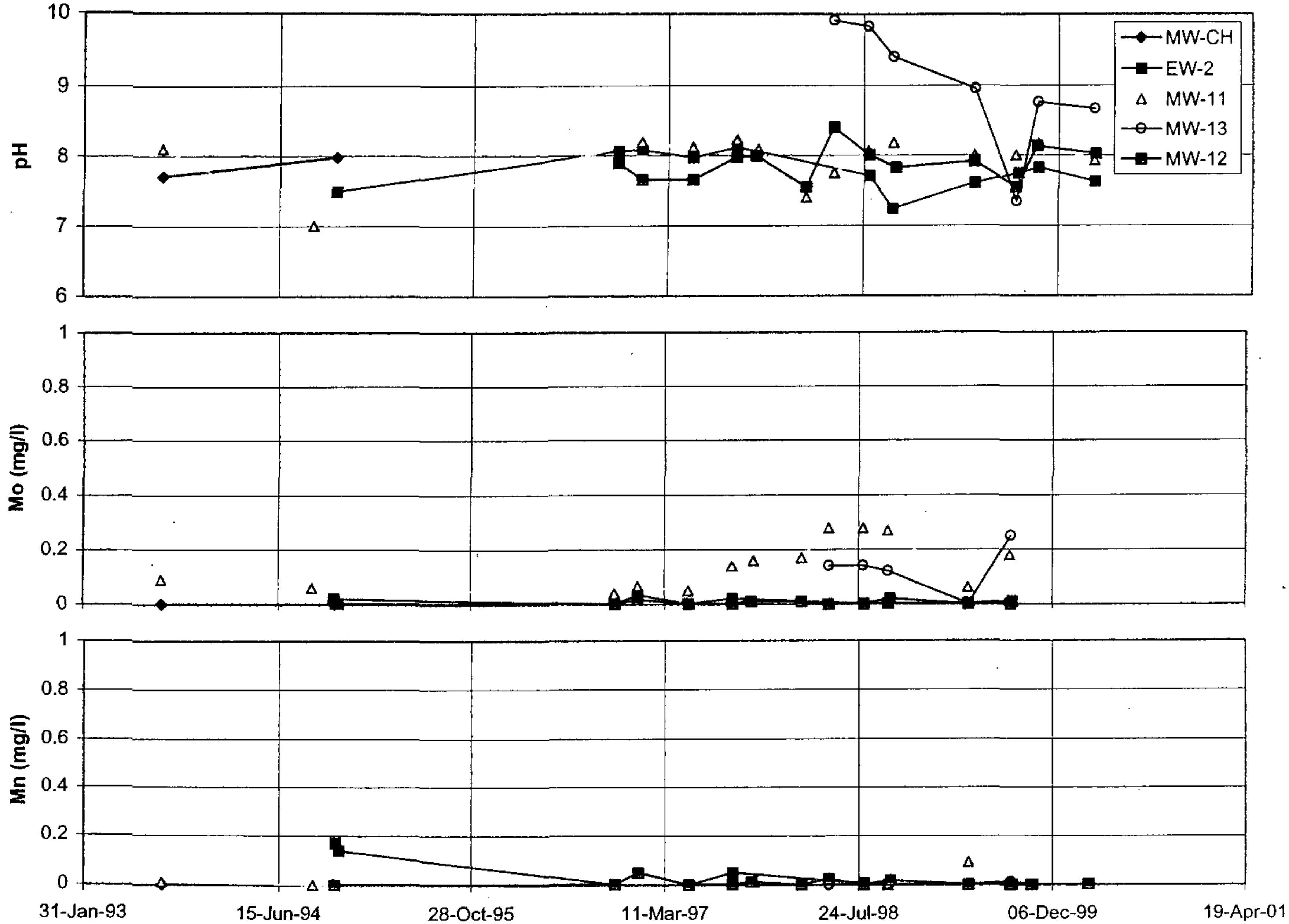
M-00001838

Figure 27b. pH, Mo, and Mn in groundwater monitoring wells located east of Dam 1 arroyo.



M-00001839

Figure 28a. SO4, F and groundwater elevations in monitoring wells in deep aquifer system.



M-00001840

Figure 28b. pH, Mo, and Mn in groundwater monitoring wells in deep aquifer system.

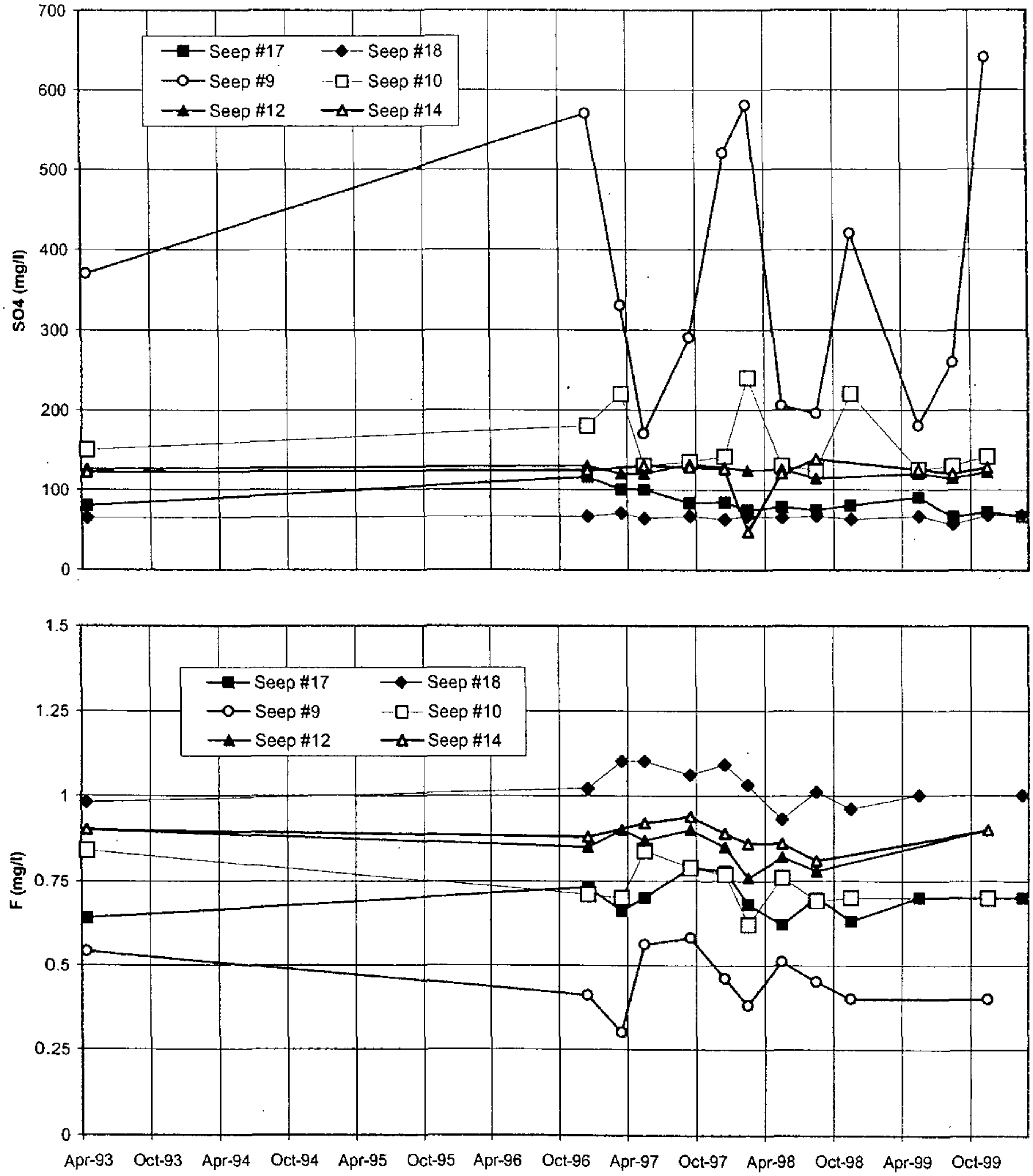


Figure 29a. F and SO4 in springs in the lower Red River basin (1993-2000).

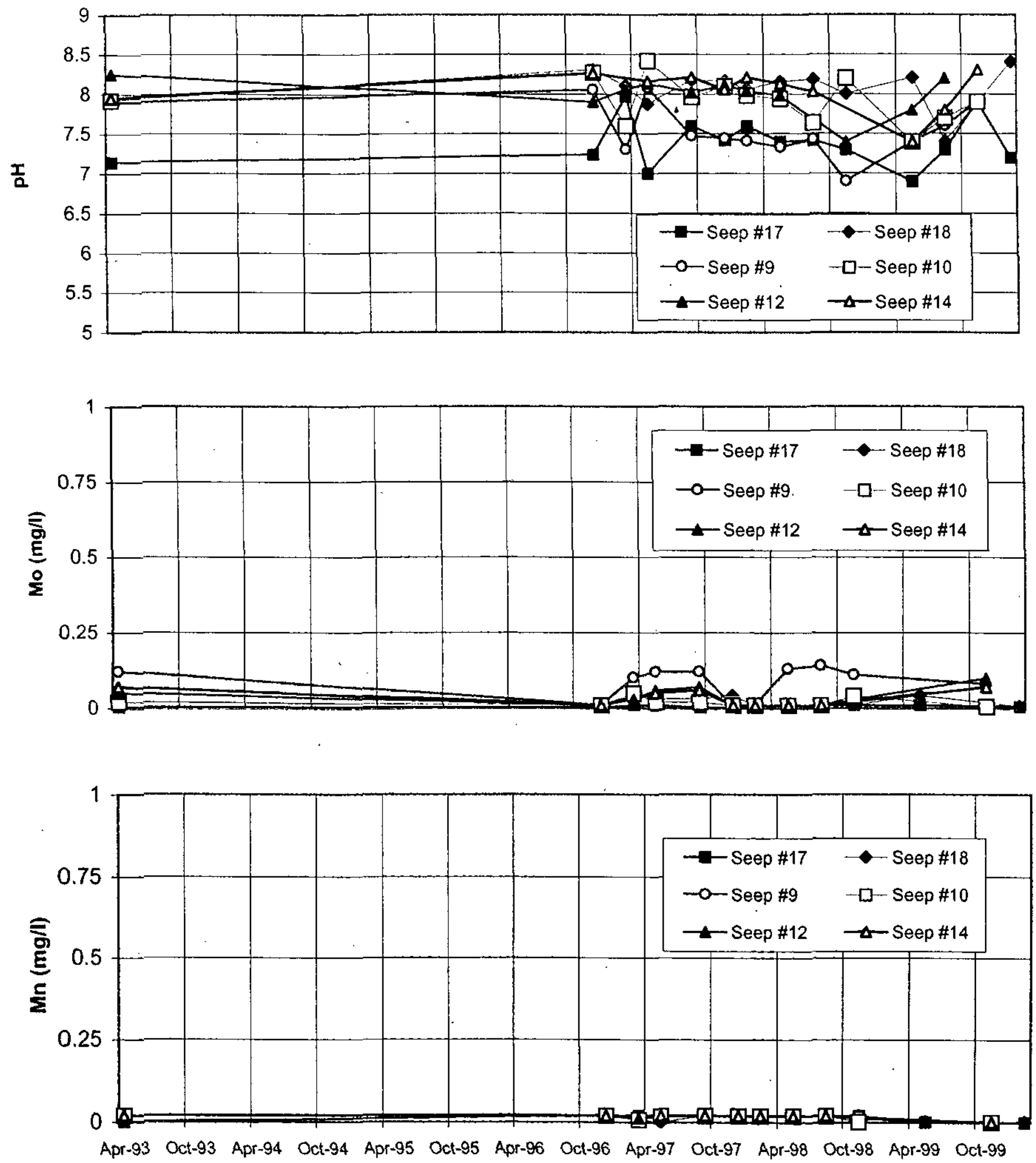
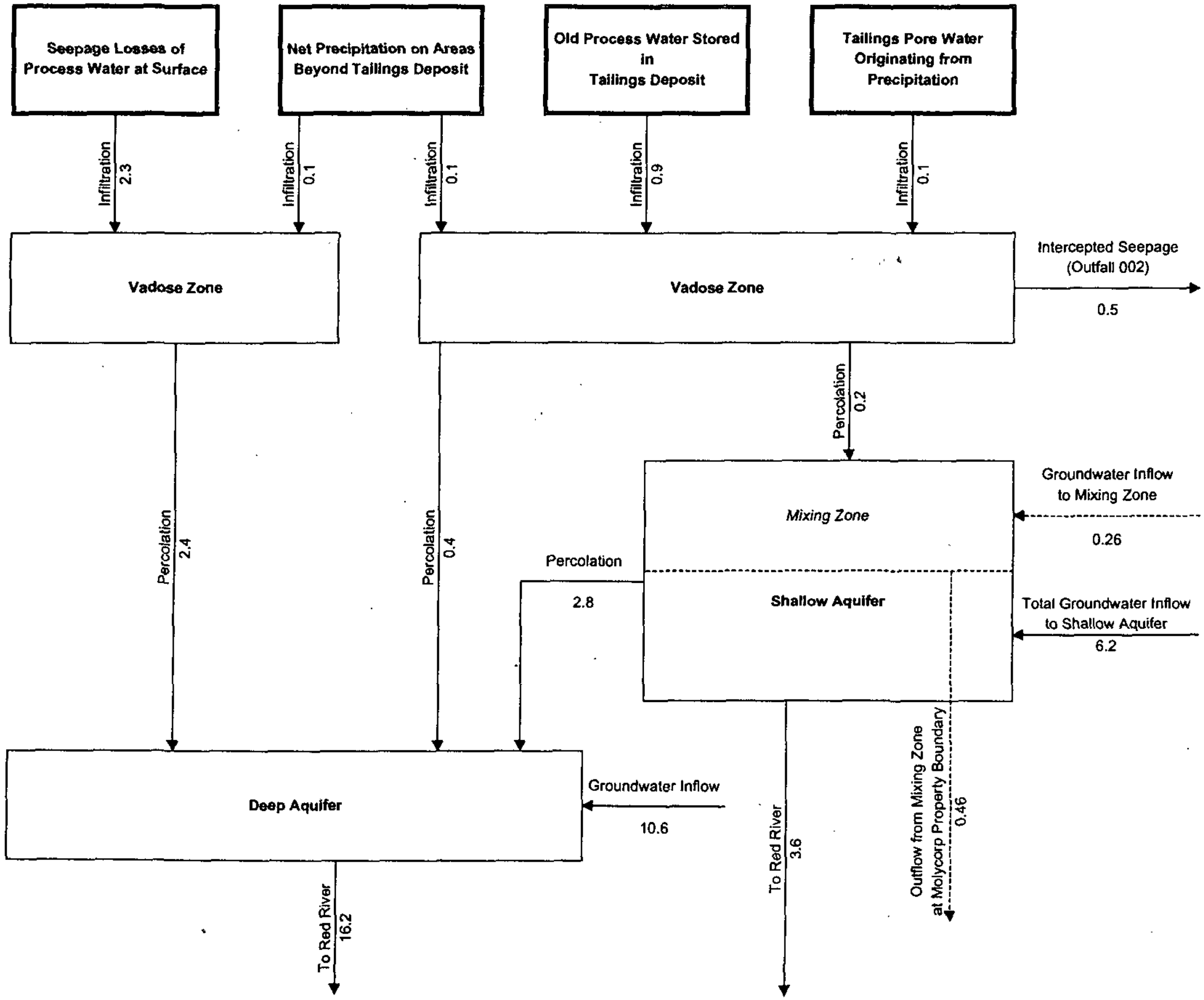


Figure 29b. pH, Mo, and Mn in springs in the lower Red River basin (1993-2000).



M-00001843

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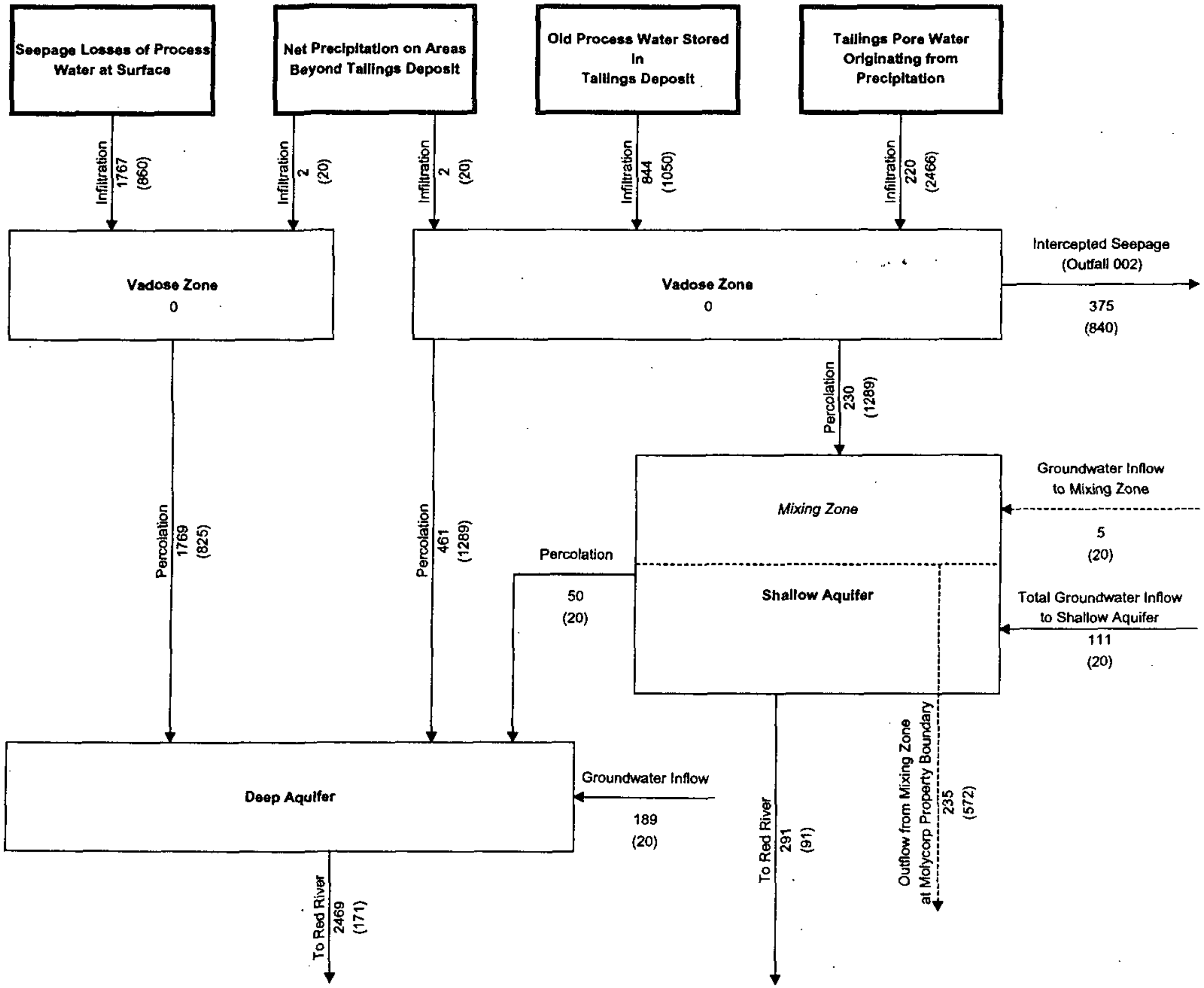
Figure 30. Estimated Average Annual Water Balance (ft^3/s).



Note: Numbers in brackets represent concentration in milligrams per litre.

M-0001844

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Figure 31. Estimated Average Annual Sulphate Balance (tonnes)

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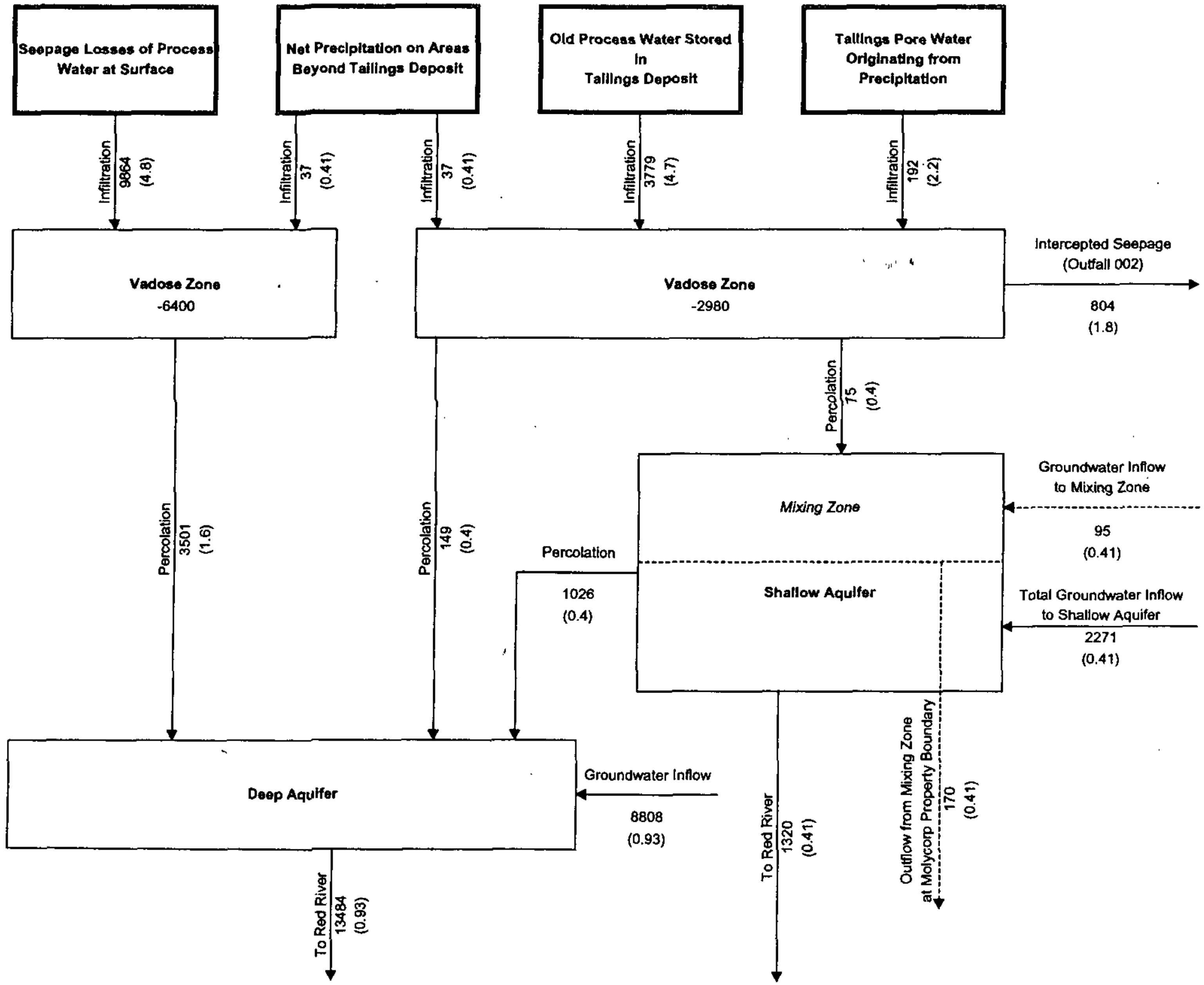
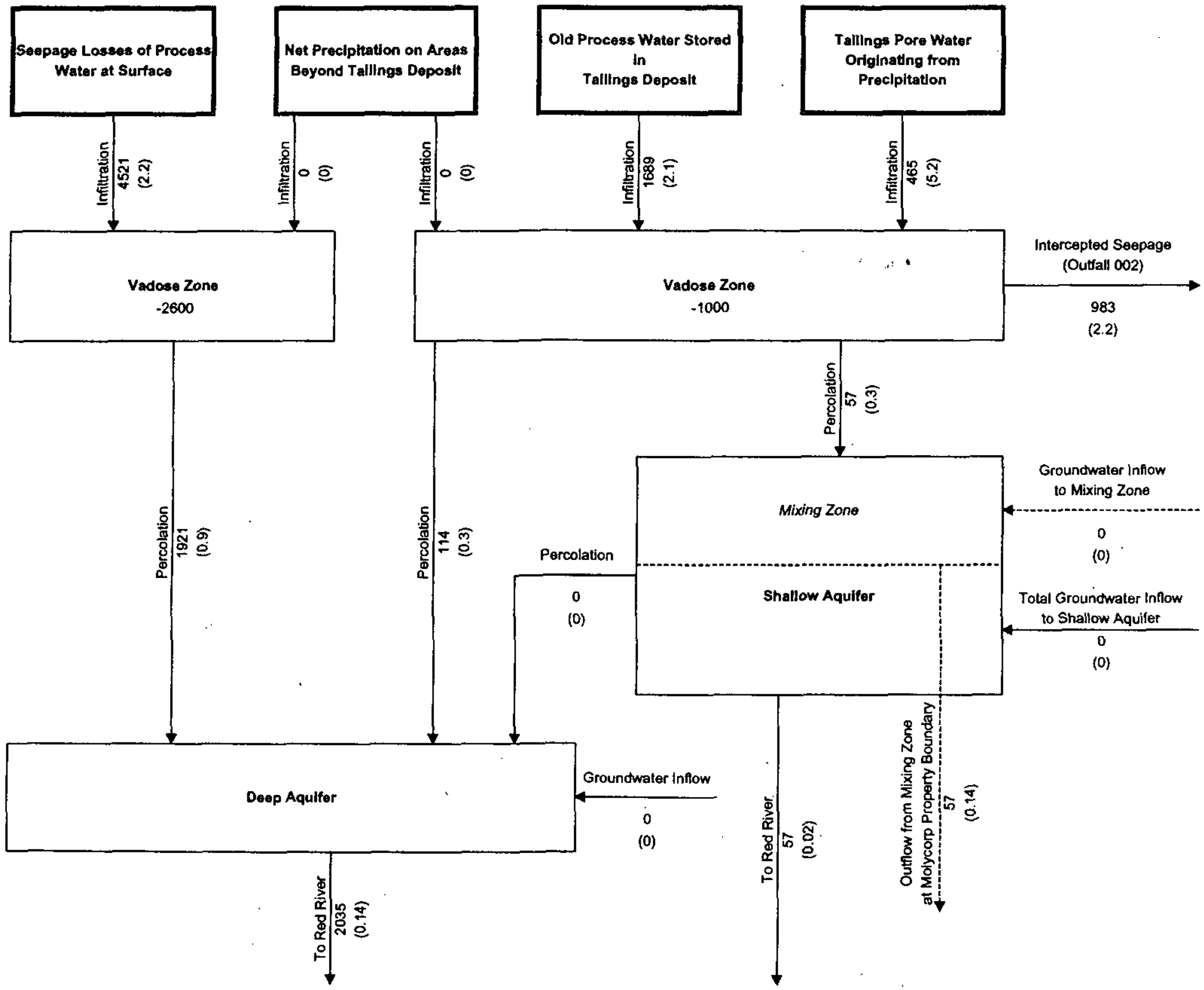


Note: Numbers in brackets represent concentration in milligrams per litre.

M-00001845

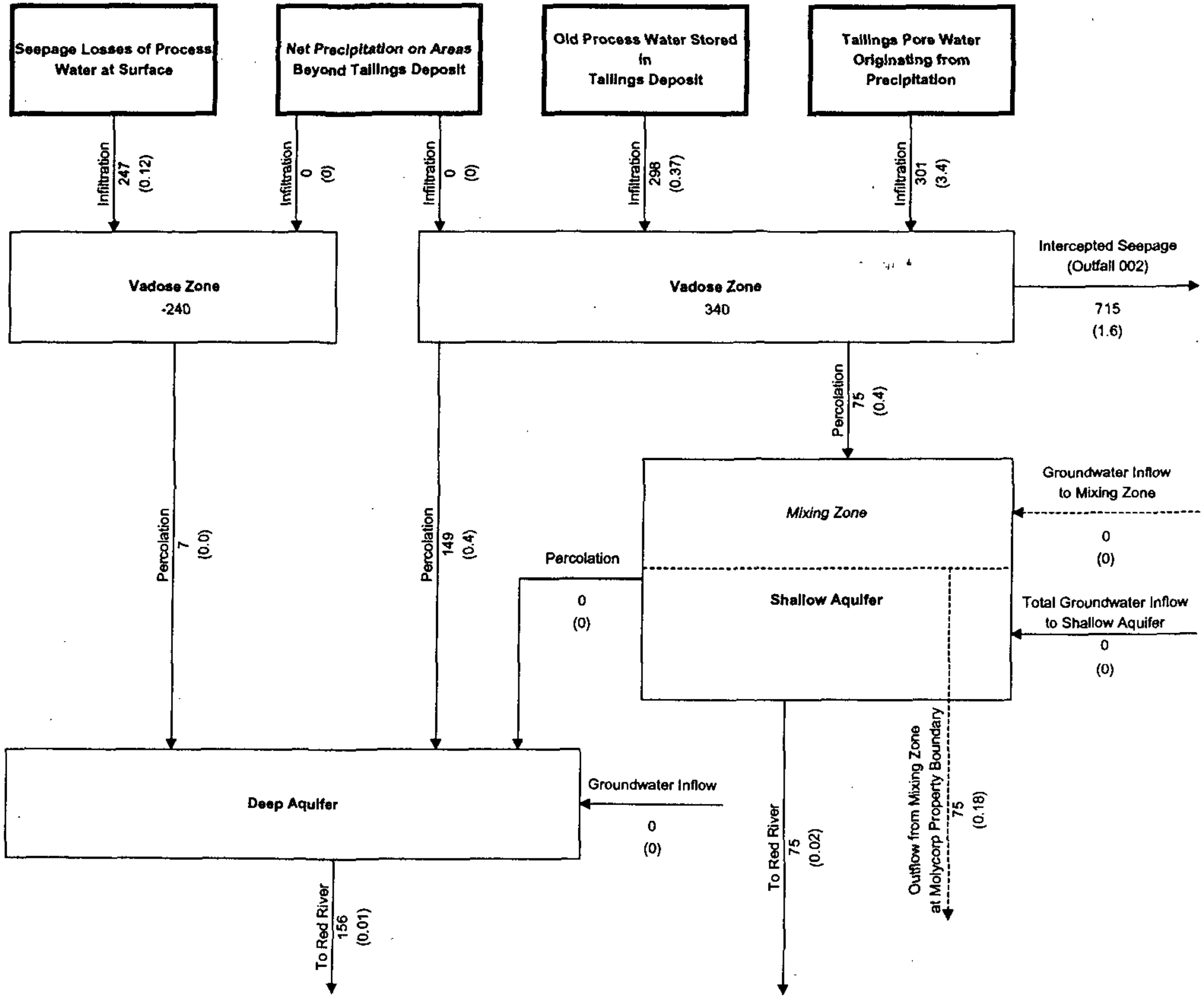
Figure 32. Estimated Average Annual Fluoride Balance (kg).



Note: Numbers in brackets represent concentration in milligrams per litre.

M-00001846

Figure 33. Estimated Average Annual Molybdenum Balance (kg)



Note: Numbers in brackets represent concentration in milligrams per litre.

M-0001847

Figure 34. Estimated Average Annual Manganese Balance (kg)

Table A1 EAC Curve for Section 36 Tailings Impoundment

This table provides an approximate EAC relationship for the period up to and including 1974. The impoundment was created by the construction of Dam 1 in the Section 36 arroyo. Dam 2 provided containment of tailings to the north. Tailings were deposited in area east of the present Dam 1B. No explicit allowance has been made for increased storage resulting from excavation of borrow sites within tailings impoundment. All incremental volumes were scaled by a factor of 1.05 (see text for explanation).

Volume (1000 m³)	Incremental Volume (1000 m³)	Elevation (ft)	Elevation (m)	Incremental Elevation (m)	Area (of horizontal slice through tailings deposit) (ft²)	(ha)	(acres)	Approximate Planimetric Area of Tailings Deposit (ha)	Incremental Planimetric Area (ha)
0	3.0	7342	2237.7	2.4	0	0.0	0.0	0.0	0.2
3.0	885	7350	2240.2	15.2	25139	0.2	0.6	0.2	10.6
888	3252	7400	2255.4	15.2	1166156	10.8	26.8	10.8	19.0
4141	7894	7450	2270.6	15.2	3209675	29.8	73.7	29.8	39.0
12035	6136	7500	2285.9	7.6	7412340	68.9	170.1	68.9	16.4
18171		7525	2293.5		9098971	84.5	208.9	85.2	

This table provides an approximate EAC relationship for the period 1975 to present. Dam 1C was constructed parallel to and upstream of Dam 1. Containment of the tailings deposit on its east side was achieved by constructing perimeter dikes (Dams 1B and 2A). A separator dike was also provided to contain the deposit on the west. Tailings deposition was made to area north of Dam 2. No explicit allowance has been made for increased storage capacity resulting from the excavation of borrow sites within the tailings impoundment. All of the incremental volumes were scaled by a factor of 1.05 (see text for explanation).

Volume (1000 m³)	Incremental Volume (1000 m³)	Elevation (ft)	Elevation (m)	Incremental Elevation (m)	Area (of horizontal slice through tailings deposit) (ft²)	(ha)	(acres)	Approximate Planimetric Area of Tailings Deposit (ha)	Incremental Planimetric Area (ha)
0	3.0	7342	2237.7	2.4	0	0.0	0.0	0.0	0.2
3.0	885	7350	2240.2	15.2	25139	0.2	0.6	0.2	10.6
888	3252	7400	2255.4	15.2	1166156	10.8	26.8	10.8	19.0
4141	8295	7450	2270.6	15.2	3209675	29.8	73.7	29.8	44.0
12435	6852	7500	2285.9	7.6	7951012	73.9	182.5	73.9	24.3
19288	28	7525	2293.5	0.0	10488971	97.4	240.8	98.1	0.0
19315	18392	7525.1	2293.5	18.0	8217586	76.3	188.6	98.1	39.5
37708		7584	2311.5		12790080	118.8	293.6	137.6	

M-00001848

Table A2 EAC Curve for Section 35 Tailings Impoundment

This table provides an approximate EAC relationship for the period up to and including 1990. The impoundment was created by the construction of Dam 4 in the Section 35 arroyo. Dam 3A provided containment of the tailings deposit to north. No explicit allowance was made for increased storage capacity resulting from the excavation of borrow sites within tailings impoundment area. All incremental volumes were scaled by a factor of 1.05 (see text for explanation).

Volume	Incremental Volume	Elevation		Incremental Elevation	Area (of horizontal slice through tailings deposit)			Approximate Planimetric Area of Tailings Deposit	Incremental Planimetric Area
(1000 m^3)	(1000 m^3)	(ft)	(m)	(m)	(ft^2)	(ha)	(acres)	(ha)	(ha)
0	440	7356	2242.0	13.4	0	0.0	0.0	0.0	6.3
440	3724	7400	2255.4	15.2	672885	6.3	15.4	6.3	34.0
4164	9890	7450	2270.6	15.2	4337492	40.3	99.6	40.3	43.0
14054	5910	7500	2285.9	6.1	8969577	83.3	205.9	83.3	18.0
19964		7520	2292.0		10910432	101.4	250.4	101.4	

This table provides an approximate EAC relationship for the period 1991 to present. Dam 5A was constructed to make use of storage available to the north of Dam 3A. No allowance was made for increased storage capacity resulting from the excavation of borrow sites within the tailings impoundment area. All of the incremental volumes were scaled by a factor of 1.05 (see text for explanation.)

Volume	Incremental Volume	Elevation		Incremental Elevation	Area (of horizontal slice through tailings deposit)			Approximate Planimetric Area of Tailings Deposit	Incremental Planimetric Area
(1000 m^3)	(1000 m^3)	(ft)	(m)	(m)	(ft^2)	(ha)	(acres)	(ha)	(ha)
0	440	7356	2242.0	13.4	0	0.0	0.0	0.0	6.3
440	3724	7400	2255.4	15.2	672885	6.3	15.4	6.3	34.0
4164	11066	7450	2270.6	15.2	4337492	40.3	99.6	40.3	57.7
15230	7306	7500	2285.9	6.1	10551616	98.0	242.2	98.0	32.3
22536	25	7520	2292.0	0.0	14024836	130.3	321.9	130.3	0.0
22561	3783	7520.1	2292.0	7.6	3114404	28.9	71.5	130.3	37.1
26344		7545	2299.6		7106777	66.0	163.1	167.4	